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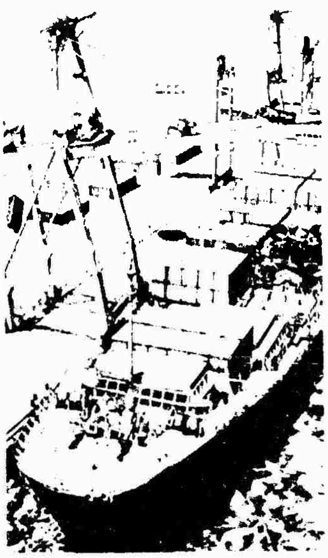

TECHNICAL REPORT GL-87-12

EVALUATION AND REPAIR OF WAR-DAMAGED PORT FACILITIES

REPORT 3
CONCEPTS FOR EXPEDIENT WAR-DAMAGE REPAIR OF PIER AND WHARF DECKING

by

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June 1987

Report 3 of a Series

Prepared for DEPARTMENT OF THE ARMY
US Army Corps of Engineers
Washington, DC 20314-1000

Under Project AT40, Task CO, Work Unit 009

Monitored by Geotechnical Laboratory
US Army Engineer Waterways Experiment Station
PO Box 631, Vicksburg, Mississippi 39180-0631

GEOTECHNICAL LABORATORY

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

ADA 183488

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY 2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
4. PERFORMING ORGANIZATION REPORT NUMBER(S) Technical Report GL-87-12	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Naval Civil Engineering Laboratory 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION USAEWES Geotechnical Laboratory
6c. ADDRESS (City, State, and ZIP Code) Port Hueneme, CA 93043	7b. ADDRESS (City, State, and ZIP Code) PO Box 631 Vicksburg, MS 39180-0631
8a. NAME OF FUNDING / SPONSORING ORGANIZATION US Army Corps of Engineers 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code) Washington, DC 20314-1000	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. — ; PROJECT NO. AT40 ; TASK NO. CO ; WORK UNIT ACCESSION NO 009

11. TITLE (Include Security Classification)
Evaluation and Repair of War-Damaged Port Facilities, Report 3; Concepts for Expedient War-Damage Repair of Pier and Wharf Decking

12. PERSONAL AUTHOR(S)
Jahren, Charles T.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final report	FROM May 1985 TO Apr 1986	June 1987	177

16. SUPPLEMENTARY NOTATION
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Container ships (LC) Harbors (LC) Military operations (LC) Transportation, Military (LC)

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The shipment of large volumes of military containerized cargo for the support of troops in the theater of operation requires sustained use of strategic ports and their facilities. The enemy may employ hostile actions to render these port facilities inoperable or to deny access to the facilities. Repairs should be conducted as quickly as possible to restore damaged port areas for the transfer of supplies from support ships to shore facilities and inland.

The purpose of this study is to analyze, develop, design, and recommend concepts that can be used for the expedient repair of container handling ports. This study also focuses on solutions to war-damaged pier and wharf decking.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code) 22c. OFFICE SYMBOL

DD Form 1473, JUN 86 Previous editions are obsolete SECURITY CLASSIFICATION OF THIS PAGE

Unclassified

PREFACE

The investigation reported herein was under the sponsorship of the Office, Chief of Engineers (OCE), US Army, and was conducted under Project AT40, Task CO, Work Unit 009, "Evaluation and Repair of War-Damaged Port Facilities." Mr. Austin A. Owen was Technical Monitor for OCE.

The study was conducted by the Naval Civil Engineering Laboratory (NCEL), Port Hueneme, California. Project engineers of the NCEL involved in this study were Messrs. L. A. LeDoux and D. A. Davis. This report documents work prepared for the US Army Engineer Waterways Experiment Station (WES) under MIPR No. A35200-5-0013 with NCEL from May 1985 through April 1986. This work was conducted under the general supervision of Dr. W. F. Marcuson III, Chief, Geotechnical Laboratory (GL), and under the direct supervision of Mr. H. H. Ulery, Jr., Chief, Pavement Systems Division (PSD), GL. Personnel of the PSD involved in this study were Messrs. H. L. Green and R. H. Grau. CPT John W. Talbot, PSD, was instrumental in the initial liaison and coordination of this study with NCEL. Mr. C. T. Jahren, a summer employee at NCEL and engineer from Purdue University, prepared the initial writing of this report. This work was coordinated and monitored by Mr. C. J. Smith, PSD. This report was edited by Ms. Odell F. Allen, Information Products Division, Information Technology Laboratory.

COL Allen F. Grum, USA, was the previous Director of WES. COL Dwayne G. Lee, CE, is the present Commander and Director. Dr. Robert W. Whalin is the Technical Director.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
cubic yards	0.7645549	cubic metres
feet	0.3048	metres
gallons per square yard	4.5273	cubic decimetres per square metre
inches	2.54	centimetres
kips (force)	4.448222	kilonewtons
kips (force) per inch	175.1268	kilonewtons per metre
kips (force) per square inch	6.894757	megapascals
mils	0.0254	millimetres
miles (US statute)	1.609347	kilometres
pounds (force) per foot	14.5939	newtons per metre
pounds (force) per square foot	47.88026	pascals
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
tons (2,000 pounds, mass)	907.1847	kilograms
yards	0.9144	metres

EVALUATION AND REPAIR OF WAR-DAMAGED PORT FACILITIES

Report 3

CONCEPTS FOR EXPEDIENT WAR-DAMAGE REPAIR OF PIER AND WHARF DECKING

1.0 Introduction

1.1 Background

The shipment of large volumes of military containerized cargo for the support of troops in a Theater of Operations (TO) requires sustained use of ports. The enemy may employ hostile actions to deny the use of these important facilities. The Army's Port Construction Companies (PCC's) are responsible for restoring the port to operation. Recent changes in the marine shipping and military doctrine require the development of improved and standardized remedies for war-damaged ports.

The PCC's will not have the luxury of time for planning or preparation, and repair materials and support resources which are taken for granted during peacetime may not be available at the damaged facility. The construction forces may have to design repairs without help from outside experts and install the repairs using only their own equipment and personnel. The goal is to provide temporary repairs in the shortest possible time using only the PCC's organic equipment and personnel, onsite salvaged material, and a modest amount of repair components which may be prepositioned at the port or sea-lifted to the TO.

This is the third of four reports on the subject work unit which focuses on solutions for pier and wharf problems encountered above the waterline. A parallel effort undertaken by the Naval Civil Engineering Laboratory (NCEL) to develop below waterline pier and wharf repair solutions is presented in report 4. Report 2 is a Waterways Experiment Station (WES) study which presents a port vulnerability analysis and identifies expedient repair systems for war-damaged piers/wharves, storage areas, and hardstands. Report 1 identifies port construction in previous military conflicts, provides information for war-damaged port assessment, and presents compendiums of major ports with special characteristics.

1.2 Generic Ports

The WES chose the Norfolk Naval Station (NAVSTA) and Norfolk International Container Terminal (NICT) as representative port facilities which will be used in this study to illustrate expedient repair techniques. The author chose Piers 7 and 10 at NAVSTA for further study. Pier 7 is an old pier, and Pier 10 is the latest pier design at NAVSTA. At the time this report was written, Pier 10 had not been constructed. WES chose a container berth as the generic structure within NICT. The design of the container wharf at NICT is typical of construction used at other commercial ports.

1.3 Damage Scenario

The damage scenario was based on a vulnerability study supplied by WES. Wharf damage is inflicted by 500 lb* general purpose bombs which explode on impact and leave craters which average 8.4 ft in diameter. Since some craters will be larger than average, it is necessary to assume a maximum crater size for repair planning. The spacing between pile caps for Piers 7 and 10 and the container berths are 12, 18, and 20 ft respectively. Some of the contemplated repairs are designed to cover these span lengths because it may be more efficient to replace a complete span rather than to patch a hole. The report will provide repair methods for spans up to 40 ft. This will allow engineers to bridge over damaged pile caps and make the effectiveness of repair methods less dependent on the damage scenario.

Based on study of the WES threat analysis report, it is assumed that there may be between 5 and 12 holes to repair in a 1,000-ft container berth.

Visits to Army Port Construction units, conversations with Army personnel, liaison with Seabee personnel, and inspection of military documents have given the author insight about the deployment of PCC's in an expedient repair situation.

CDR G. Spence, CEC, USNR ADIC Program Information Branch, Regional Wartime Construction Manager, Mediterranean Code N961 CINCUSNAVEUR reserve units,

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 4.

informed the author that there are three main alternatives considered in repairing a war-damaged port. They are pursued as follows:

a. Ask the host country to repair the facility.

b. Hire a contractor.

c. Have a military construction unit do the work.

The deployment procedure for a PCC was determined during conversations with CPT Dave Washechek, Commanding Officer, 497th Engineer Company (Port Construction (PC), on 13 June 1985. The PCC would be attached to a combat heavy engineer battalion which would give the PCC nonspecialized engineering support as necessary. The full equipment allowance would be sealifted to the TO and the men would be airlifted in time to meet the equipment.

Upon arrival in the TO, the PCC is responsible for the following:

a. Installation of De Long Piers.

b. Deployment of POL (petroleum, oils, and lubricants) pipelines.

c. Rehabilitation of ports.

Only one-third of the company would be available for port rehabilitation until items a and b are complete. However, unspecialized help would be available from the combat heavy engineer battalion to which the PCC is attached.

LTC Paul Troxler, 416th Engineer Command, explained that expedient repairs are expected to last for a 6 month duration. The planner should make decisions which minimize repair time. No consideration is given about how expedient repairs will hinder permanent restoration of the port when peacetime returns.

1.4 PCC Capabilities

The author visited two PCC's during this study: the 497th Engineer Company (PC) at Fort Eustis, Va., which is the only Regular Army PCC, and the 801st Engineer Company (PC), which is a reserve unit based in Oakland, Calif. The following is a list of the 497th resources and limitations based on the author's observations:

1.4.1 Resources.

a. The unit is most effective in timber construction. It also has sufficient welding capability to do light steel construction.

b. The unit exhibits good teamwork skills and ability to improvise when necessary.

c. Organic cranes, piledriving equipment, and trucks are adequate for light work.

d. Extra officers are available to coordinate complex projects and to manage geographically dispersed operations.

1.4.2 Limitations

a. There is insufficient training time in heavy marine construction. There is also not enough training scenarios which simulate container port repair.

b. There is insufficient training time in concrete construction.

c. Rotation of personnel and lack of training manuals inhibits buildup of marine construction expertise.

d. Floating equipment is improperly repaired.

The resources and limitations of the 801st Engineer Company (PC) are similar to those of the 497th. The 801st is a reserve unit, and there are some differences. The 801st does not have as much equipment available to it as the 497th, and combat skills are not as well refined. However, the 801st does not experience as much personnel rotation as the 497th. This results in a buildup of construction knowledge and better teamwork skills.

At this time the PCC's do not have capability of effecting repairs which involve heavy concrete work, heavy pile driving, or heavy lifting from floating equipment. The existing PCC's have the potential to perform this type of work if given the proper equipment and training. Presently, they have the capability of performing simple repairs, especially if they involve the use of timber or steel.

1.5 Design Criteria

Direction from WES provided the following design criteria for repairs designed under this work unit:

a. Must be constructible by Army PC units supported by other Army engineer construction units using only organic personnel and equipment. The researcher should assume that full equipment allowance is available and in good repair and that personnel are properly trained for their jobs.

b. Must be as capable as the original structure of withstanding expected container-handling loads from the heaviest military cranes and cargo handlers.

c. Must be as capable as the original structure of supporting maximum uniform live load of 1,000 lb/sq ft.

d. Must be expediently constructible.

e. Must include required bracing and support from undamaged portions of the structure and expediently built substructure supports.

f. Must be constructed from materials which are available within the TO or easily sealifted.

g. Must not include military bridging or airfield landing mat.

Repairs to crane rails are not included in this work unit. Based on information supplied by port authorities, WES researchers assume that crane rail repair is too time-consuming and too intricate to warrant study at this time.

2.0 Sources of Information

Information for this report came from the following sources:

a. Army field manuals and technical manuals.

b. Department of Defense reports. Special emphasis was placed on reviewing Navy documents which might be unfamiliar to Army researchers.

c. Personnel contacts and site visits. The following were most helpful in preparing this report:

   (1) LTC Paul Troxler, 416th Engineer Command, Chicago, Ill.

   (2) 497th Engineer Company (PC), Fort Eustis, Va.

   (3) 801st Engineer Company (PC), Oakland, Calif.

   (4) Norfolk Naval Station, Staff Civil Engineers Office.

   (5) Norfolk International Container Terminal.

d. Nonmilitary sources were consulted concerning the availability of material and the possibility of new construction techniques.

The references and bibliography (Appendix A) contain complete information.

3.0 Generation and Selection of Alternatives

The steps below were followed during execution of this study:

a. Problem definition and information gathering (Sections 1.0 and 2.0).

b. Generation of alternatives (Section 3.1).

c. Selection of alternatives for final design (Section 3.2).

d. Design of selected alternatives (Sections 4.0 through 8.0).

e. Comparison of selected alternatives (Section 9.0).

3.1 Generation of Alternatives

Alternative solutions were generated in two steps. In the first step, conventional solutions are developed based on findings from the problem definition and information gathering stage.

a. Cover damaged areas with steel plates.

b. Form and place a concrete patch.

c. Use underslung steel beams to support a temporary timber deck (see Figure 3.1).

d. Construct prefabricated timber and steel deck elements (see Figure 3.2).

e. Prefabricate concrete beams.

f. Drive sheet piling to form a circular cell and fill it with rubble (see Figure 3.3).

These ideas were used to stimulate discussion at an innovation session which was held at the NCEL. Researchers who had an interest in expedient repair were invited to attend. Those present were encouraged to offer alternatives without regard to physical and economic feasibility or study limitations. Discussion was centered around the following areas:

a. A change of container handling methods so the use of damaged areas is not necessary.

b. The use of locally salvaged material.

c. The use of floatation for support.

d. The use of piling.

e. The use of devices that attenuate the load or transfer it to undamaged areas.

f. The use of bridging methods.

g. The confinement of materials, such as dirt or rubble, in such a way that they support a load without spilling out into the berth.

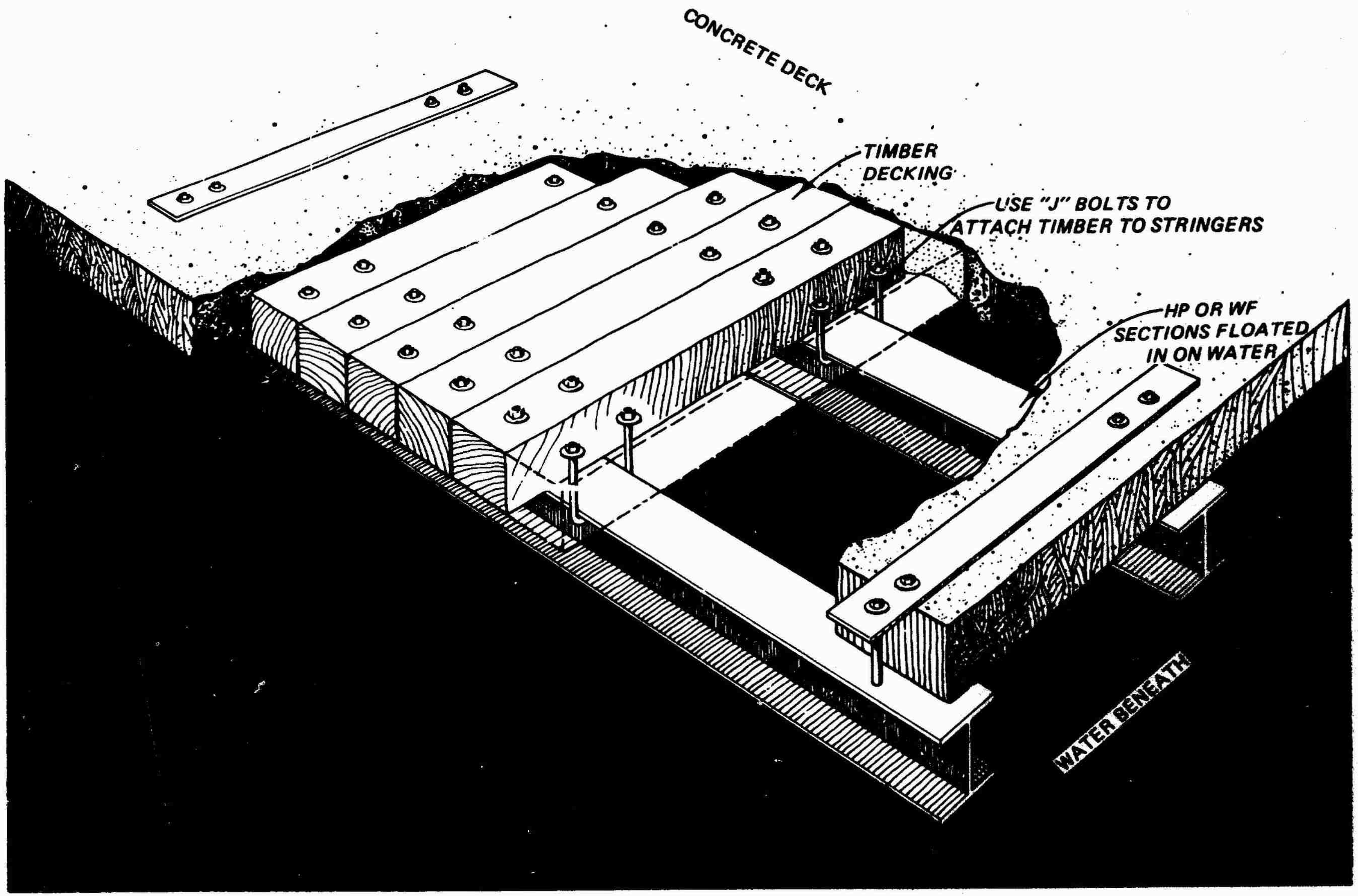


Figure 3.1. Underslung steel beam and timber deck repair

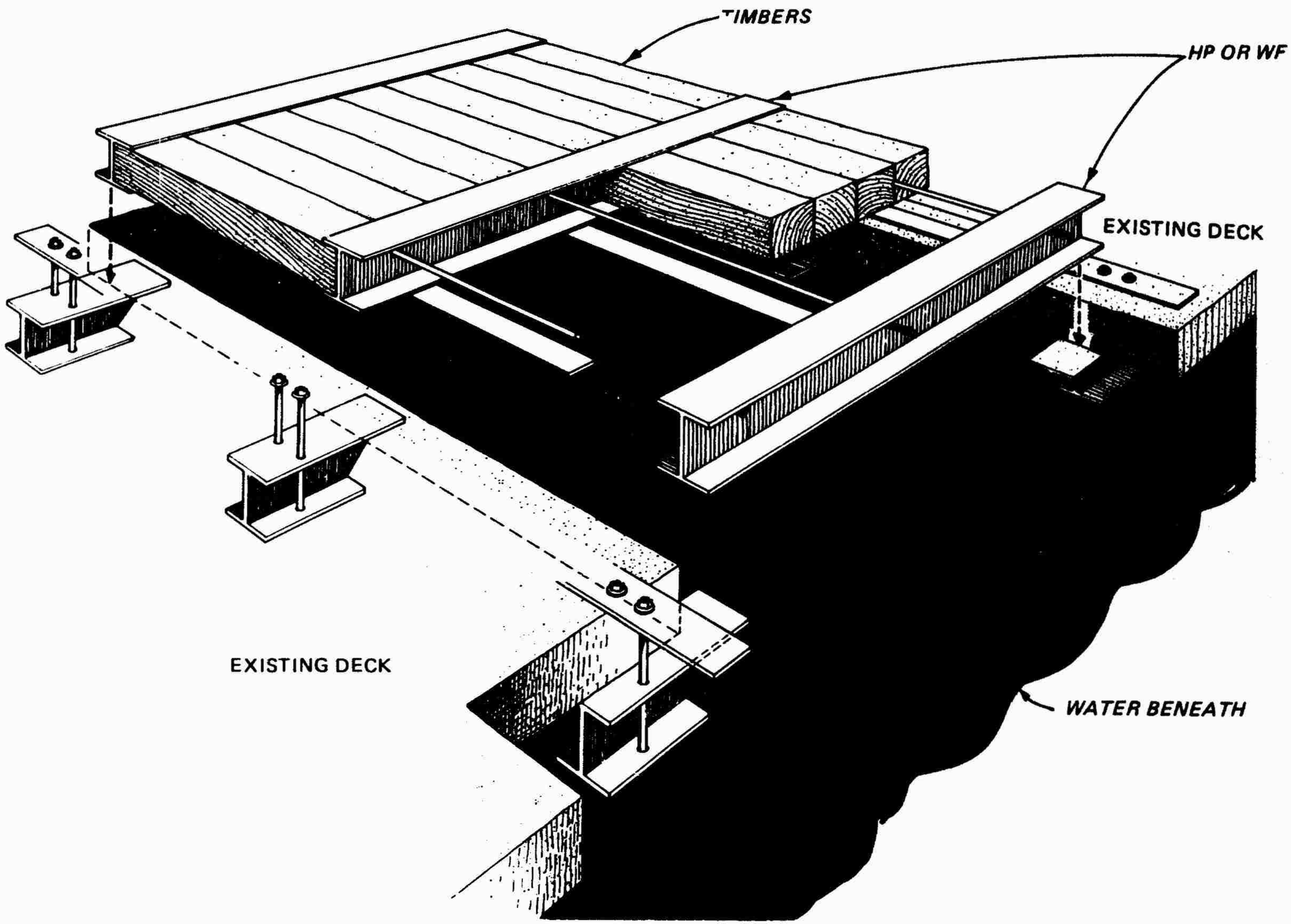


Figure 3.2. Prefabricated timber and steel deck panels

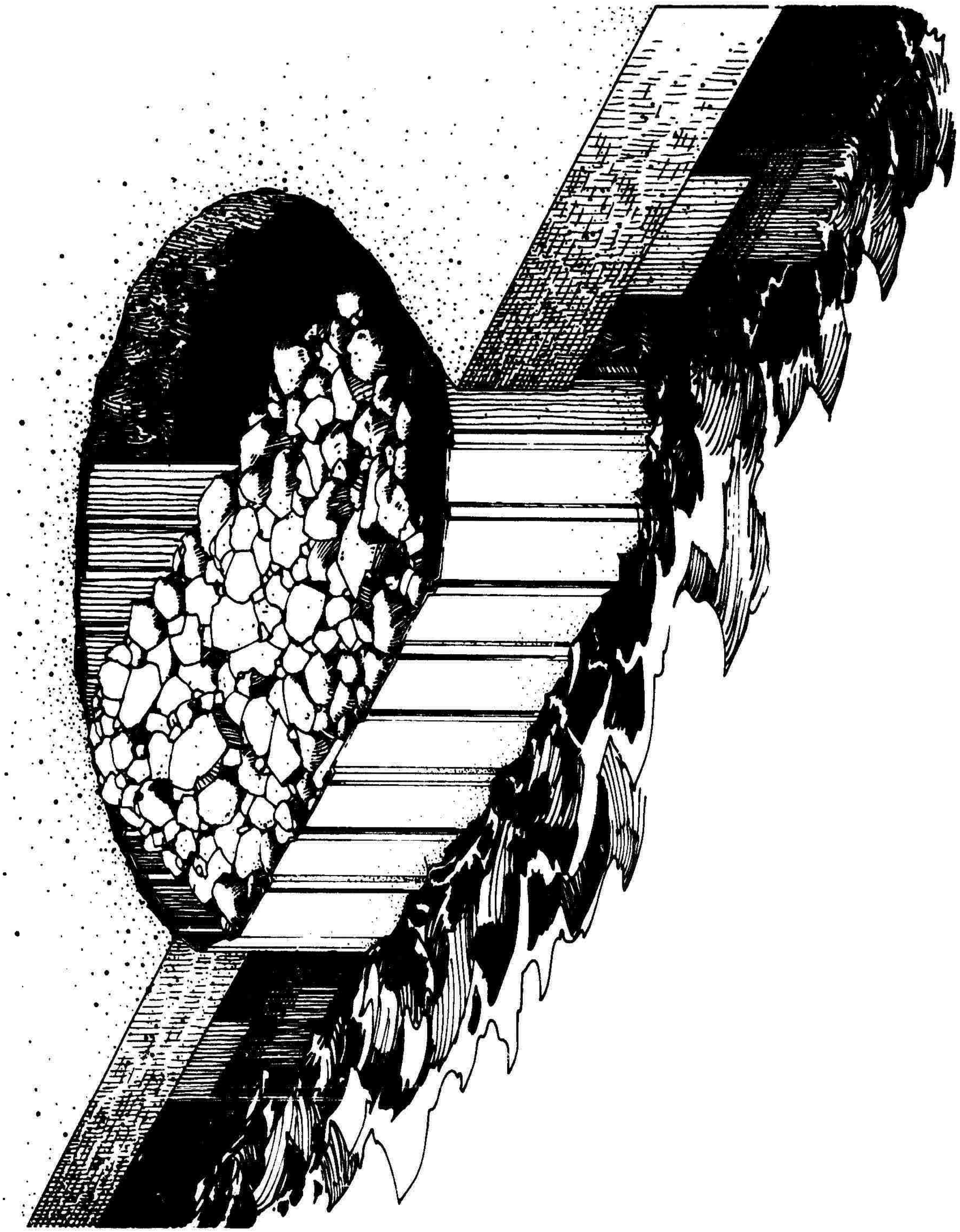


Figure 3.3. Circular sheet pile cell filled with rubble

3.2 Alternative Selection

The list of conventional alternatives and the results of the innovation session were forwarded to WES researchers. The list was reviewed by WES, comments were made, and more innovations were added to the list. In a joint meeting between WES and NCEL researchers the following selection criteria for alternatives were adopted:

a. Low technology solutions have preference over high technology solutions because of PCC training and equipment.

b. Use of off-the-shelf and salvaged materials should have preference over special order items because of procurement, transportation, and cost problems.

c. The use of concrete should be avoided because of the preference of the PCC, the potential difficulty locating aggregate and water, and problems waiting for curing time. Also, parallel research on concrete repairs is being done by another team at WES.

d. At least one solution involving the use of timber and steel bridging should be studied because of the preferences of the PCC.

e. Items such as pile cap repair, quay wall repair, concrete cutting, and an investigation of the strength the deck adjacent to damaged areas should be included for the sake of completeness.

Complete information on the innovation process is contained in Appendix B. Ideas not used in this study were documented because they might help future researchers.

NCEL and WES agreed that the following topics would be fully investigated:

a. Determination of the strength of the deck adjacent to damaged areas.

b. Use of steel plates to cover damaged areas.

c. Use of steel and timber grillages to repair deck (Figures 3.1 and 3.2).

d. Development of "umbrella" concept (Figures 3.4, 3.5, and 3.6).

e. Development of expedient repair techniques for pile caps.

f. Development of expedient repair techniques for quay walls above the waterline.

g. Use of railroad flatcars as bridging devices.

h. Use of precast, prestressed concrete girders.

i. Review of methods for cutting concrete.

WES researchers made the following comments concerning the results of the innovation session:

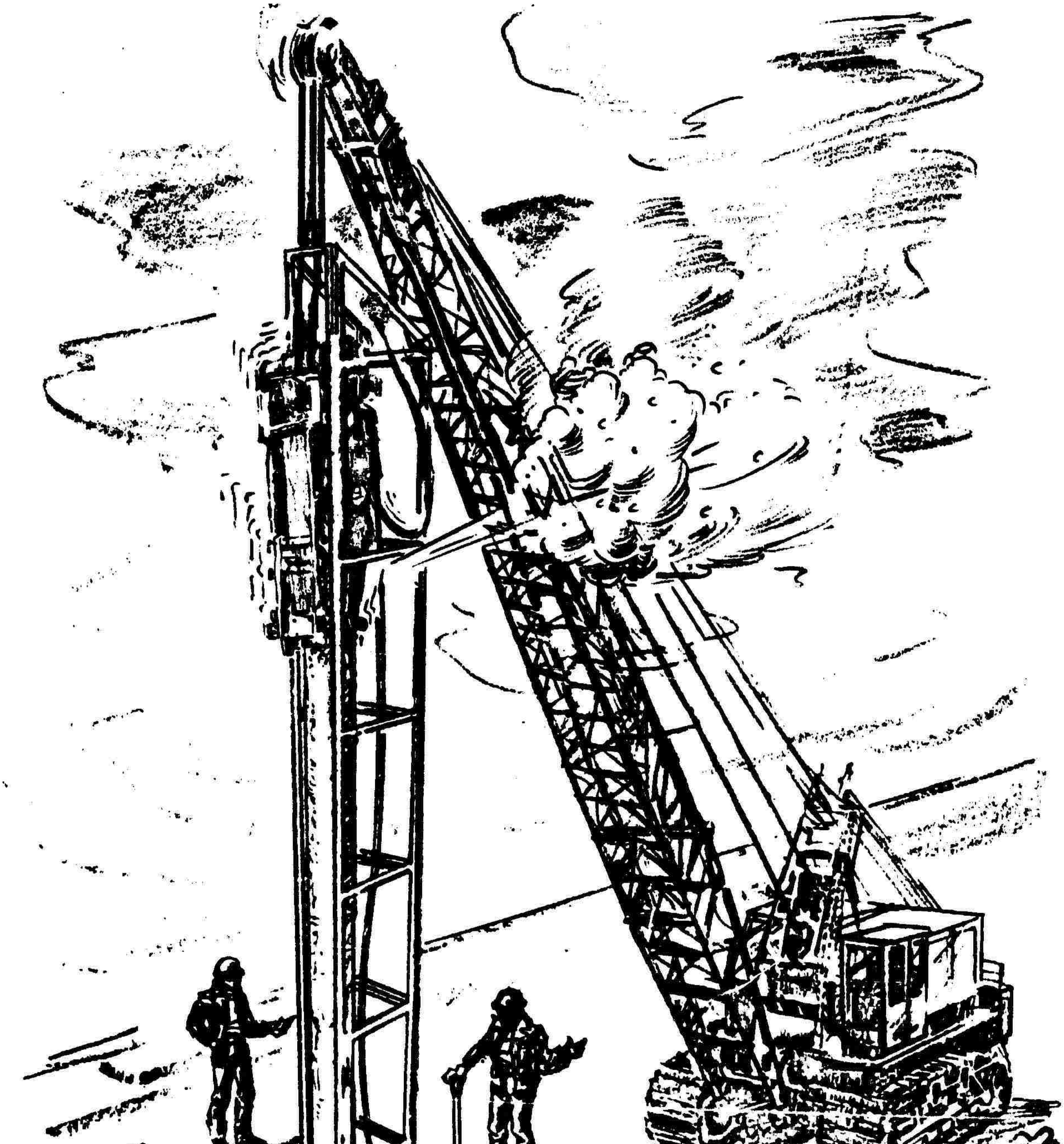


Figure 3.4. Umbrella concept, drive piling

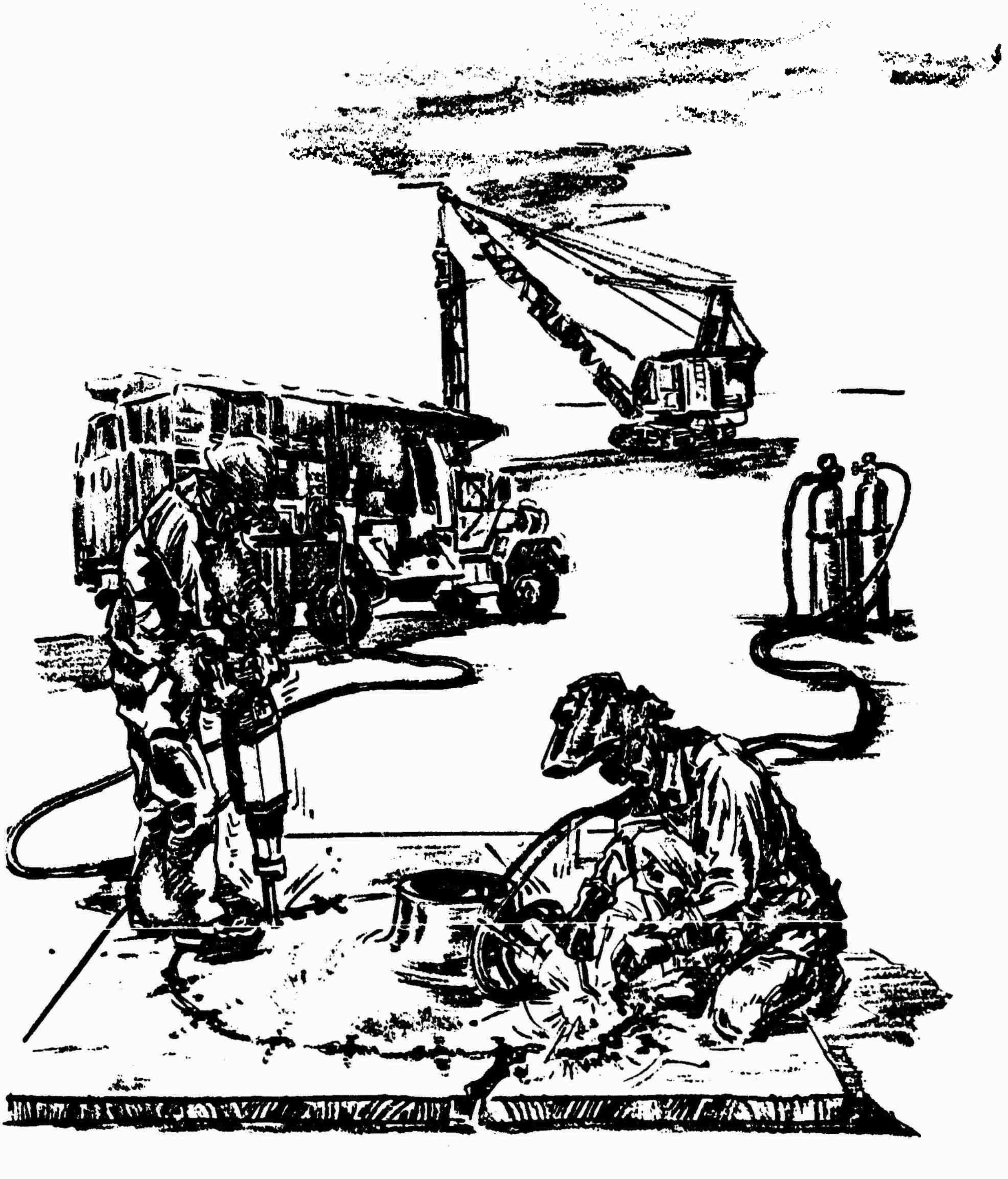


Figure 3.5. Umbrella concept, trim umbrella

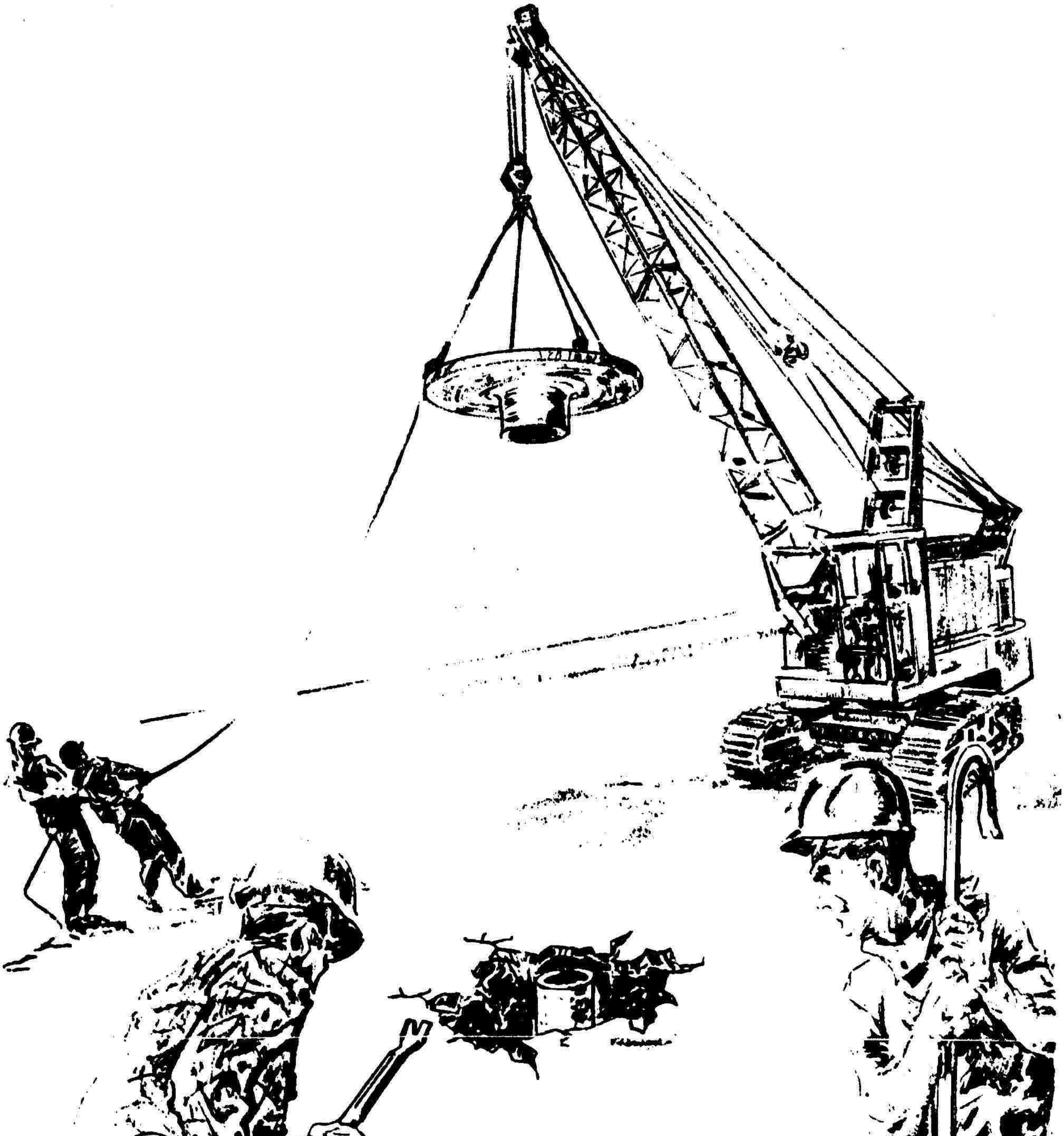


Figure 3.6. Umbrella concept, set umbrella

a. Change container handling methods. This is beyond the scope of the study.

b. Use locally salvaged material. The material available will vary so much that this solution lends itself to on-the-spot innovation rather than research. Some consideration for uses of rubble may be warranted.

c. Use of floatation support. WES expressed greater interest in other topics.

d. Use of piling. This subject will be covered under a parallel study for underwater solutions. "Umbrella" caps for piling which are driven in the center of a hole should be considered. (see Figures 3.4, 3.5, and 3.6).

e. Load attenuation devices. WES expressed no immediate interest in these solutions because they involved special materials, moving parts, and complicated assembly. (see Figure 3.7 for an example of one such device).

f. Use of bridging methods. WES expressed the greatest interest in this method.

g. Confinement of fill material. WES expressed interest in the use of containers to confine rubble or soil. Further investigation of this concept by the NCEL research team working on underwater repairs showed that containers were too weak for port repair use. Confinement of rubble with sheet piling (Figure 3.3) was rejected because it is too complicated. Driving sheet piling in rubble bottom would be difficult.

4.0 Material Availability

4.1 Procurement Procedures

The expedient repair process will be enhanced by designing solutions which use materials that are available as off-the-shelf items. The author made inquiries to suppliers and the 31st Naval Construction Regiment (NCR) Logistics Department Code R40 of Port Hueneme Construction Battalion Base concerning the availability of construction material.

The 31st NCR Logistics Department acts as an expediting organization for the Seabees. When standard procedures are used for construction materials, purchasing can be a time-consuming process. If an item is needed, the following supply methods are pursued in this order:

a. Obtain the item from a stockpile on base.

b. Obtain the item from another source within the government, such as another military base.

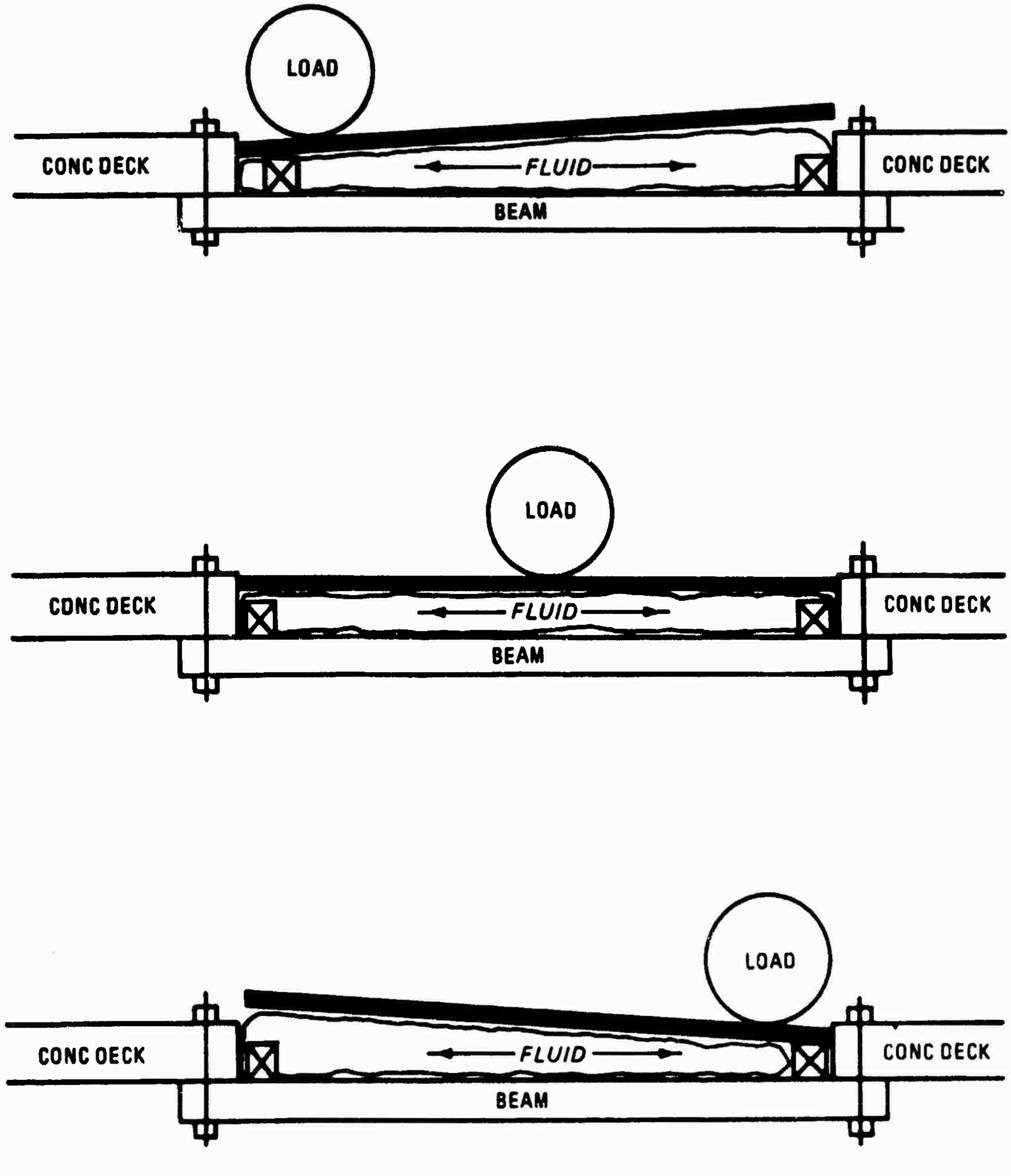


Figure 3.7. Fluid bag load attenuator

c. Obtain the item by local purchase with little difficulty if it costs less than $25,000.

d. Obtain the item by local purchase with great difficulty if it costs more than $25,000.

In an emergency situation, restrictions which slow the purchasing process are waived, and any necessary item can be purchased immediately if it is stocked by a local supplier. The purchase of materials for prepositioning could not employ this luxury. The comments concerning purchases which involve standard operating procedures were as follows:

a. It often takes 6 months to purchase something using standard operating procedures.

b. Plate steel costs three times as much to buy in small quantity using standard procedures rather than local purchase.

c. When ordering treated lumber, allow 60 days between ordering time and shipping. Items such as 90-ft utility poles are difficult to obtain.

d. Steel products such as angle iron are especially difficult to obtain using standard procurement procedures.

e. Fabricated steel products obtained under a construction contract are easily expedited.

The following is a list of suppliers contacted:

a. Allen Forest Products, North Plains, Oreg., Lumber Brokerage.

b. Bethlehem Steel Corporation, Structural Shape Sales, Bethlehem, Pa.

c. L.B. Foster, California Sales Office, Commerce, Calif., Supplier of pipe, piling, construction equipment, railroad track products, and construction equipment.

d. General Pipe, Los Angeles, Calif., Structural steel supplier.

e. Kelly Pipe, Los Angeles, Calif., Supplier of utility pipe.

f. McFarland Cascade, Tacoma, Wash.. Consumer forest products, utility poles, and timber piling.

g. Oregon Steel Mills, Steel plates rolling mill.

h. US Steel, Los Angeles Sales Office, Los Angeles, Calif., Regional warehouse for structural steel products.

i. Ziegler Steel Co., Los Angeles, Calif., Steel supplier.

4.2 Availability of Steel Products

Chicago and Pennsylvania are considered primary distribution points for structural steel. Houston is a primary distribution point for oil well products such as pipe, and Los Angeles is a secondary distribution point. If a

structural steel item was available in Los Angeles, it was considered "easily available" for the purposes of this study.

Los Angeles steel suppliers reported that lighter steel sections in each dimension were well-stocked. For example, a W36X135 section is easier to find than a W36X300 section. W sections which weighed less than 100 lb/ft were available in Los Angeles. W14 sections were especially popular and, therefore, were well-stocked. High strength steel beams are not stocked in Los Angeles.

Steel items which are not in stock may be ordered from the mill. Inspection of rolling schedules from US Steel and Bethlehem Steel indicates that wideflange (W) shapes in the 36, 24, and 21 in. sizes in lighter weights and W14 sections in most weights are rolled every other week. Most other W sections are rolled monthly. Standard beams, angles, channel, and sheet piles are rolled on an intermittent basis. If an item must be ordered from a mill, 4 to 6 weeks delivery time is required.

The availability of H-sections (HP) was investigated because this section may be used either as a pile or a beam, depending on requirements. HP10- and 12-in. sections are rolled by four steel companies: US Steel, Bethlehem, Inland, and N.W. Wire and Steel. HP14 piles are rolled by US Steel and Bethlehem only. HP sections are generally rolled every other week. Inland steel has recently started production of an HP13 section. L.P. Foster maintains a stockpile of 10,000 tons of HP pile in the Chicago area. HP12 X 53 and HP10 X 42 are most available from this stock.

High strength steel shapes are available only on special order. US Steel reports that it has a stockpile of high strength steel shapes in New Jersey. Foreign steel producers prefer to target the high strength steel market. This is because import quotas are tonnage-based; therefore, it is more profitable to sell higher-priced high strength steel.

Plate steel is easily available in thicknesses up to 2 in. and widths up to 96 in. Type A36 steel is available in greater thicknesses. High strength plates 50 to 100 ksi is not available in thicknesses greater than 2 in.

In July 1985, A36 (36 ksi) steel delivered from a warehouse in the Los Angeles area in truck load lots averaged $0.25/lb. Steel delivered by rail direct from the mill was one or two cents less per pound. Approximately $0.40/lb for 100 ksi high strength plate would be a good price to use for rough estimates.

4.3 Availability of Forest Products

Forest products such as 2-by 12-and 4-by 12-in. sections are available off-the-shelf in virtually unlimited quantities. Structural timbers such as 12-by 12-in. sections are available by special order only. It takes 2 weeks to obtain the timbers and another 2 weeks for treatment with preservatives. Wood preservation may not be necessary unless storage is contemplated. Timbers in lengths greater than 24 ft are difficult to obtain, even on a special order basis. Poles are commonly available in lengths from 20 to 40 ft and butt diameters up to 13 and 14 in. Treated poles take 30 to 45 days to deliver and cost $6.00/ft. Gluelam products are usually delivered 4 to 5 weeks after an order is placed, if factories are not too busy.

5.0 Critical Design Loads

The following design loads acting on the deck of piers or wharves were chosen by WES for use in this study (see Appendix C for load design configurations):

- a. 1,000 lb/sq ft uniform load
- b. 80-ton crane
- c. 140-ton crane
- d. Harnischfeger 250-ton truck crane (P&H 6250 TC)
- e. Shoremaster straddle carrier
- f. Clark 512 straddle carrier
- g. Belotti straddle carrier
- h. 4,000-lb forklift
- i. Hyster 620B forklift
- j. Caterpillar 988 forklift (Cat 988)
- k. M52 tractor with XM871 trailer
- l. XM878 tractor with XM872 trailer
- m. M915 tractor with XM872 trailer
- n. M911 heavy equipment transporter

The design loads which caused the most moment and shear in simple spans less then 30 ft long were the P&H 6250 TC 250-ton truck crane, Cat 988 forklift, and 1,000 lb/sq ft uniform load. The maximum shear and moment caused by this equipment and uniform load on a simple span is shown in Figures 5.1 and 5.2.

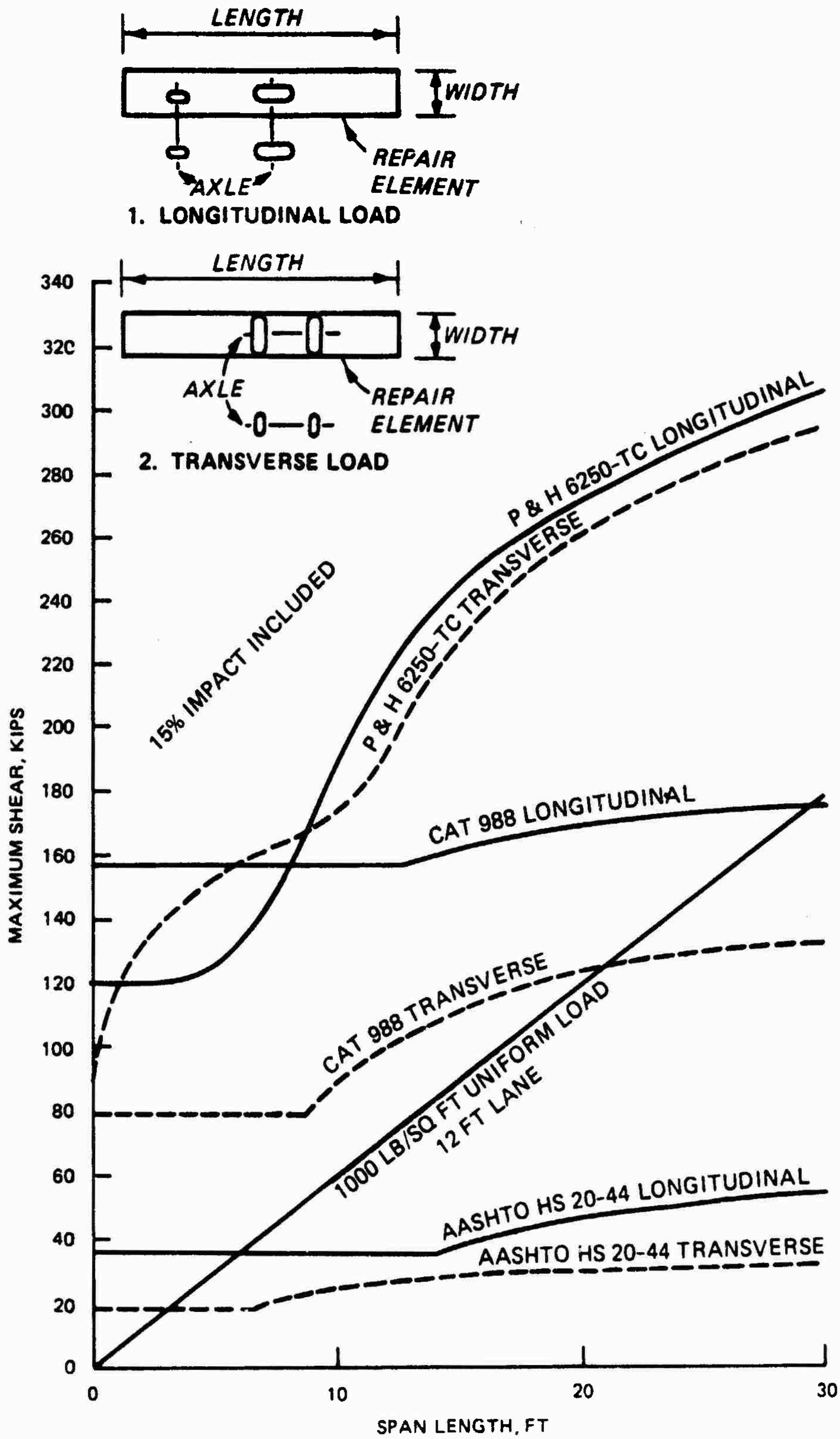


Figure 5.1. Maximum shear versus span length, impact factor: 15 percent, lane width equals 12 ft

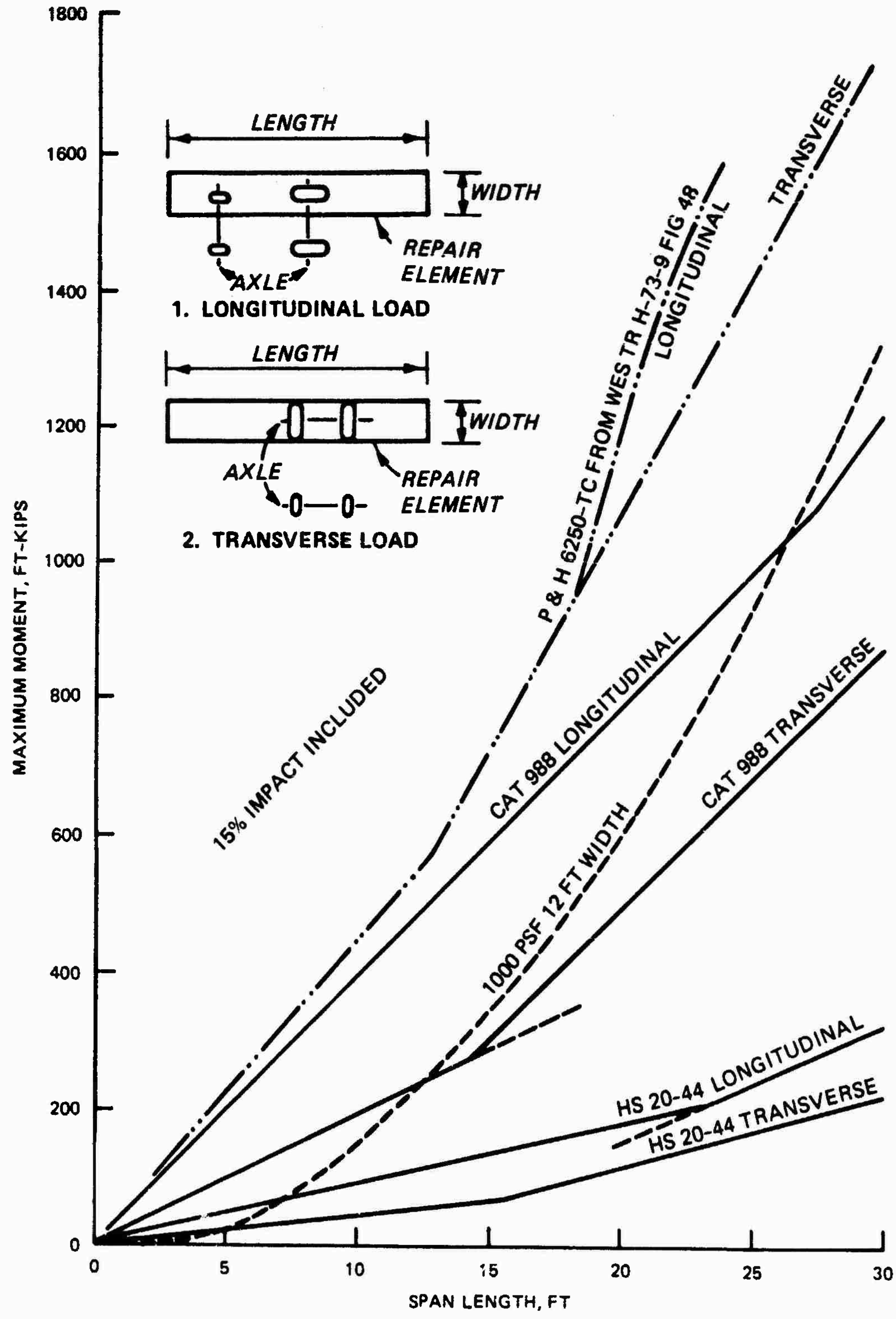


Figure 5.2. Maximum moment versus span length, 12-ft lane, 15 percent impact factor

Longitudinal and transverse load relationships are also presented. Span lengths for most piers are less than 30 ft, and many available repairs involve simple span bridging. Figures 5.1 and 5.2 show the problems the port engineer faces with respect to design loads. The HS 20-44 loading is the critical load for most highway bridge design (Figure 5.3 and Refs 5.1 and 5.2). The HS 20-44 load effect is also plotted in Figures 5.1 and 5.2. Note that the use of container handling equipment puts a much greater demand on a structure than the HS 20-44 loading.

Figures 5.4 and 5.5 give general shear and moment information for longer spans and several container handling vehicles. Figures 5.6 and 5.7 give detailed shear and moment information for the Cat 998 loading on long spans. Figures 5.8 and 5.9 give detailed moment and shear information for the HS 20-44 loading on longer spans.

The weight of repairs is neglected when critical loads are determined. Most repairs do not weigh more than 100 lb/sq ft. This is insignificant compared with the 1,000-lb/sq ft uniform load. This simplification may not be justified for long spans where the HS 20-44 is the largest load considered or concrete is the repair material.

The dynamic effects of equipment movement requires a 15 percent increase in vehicle loading for design of deck components (Ref 5.2).

A vehicle may produce greater structural demand when it operates transversely to the span of the deck. This is especially true when deck components are narrow, discrete elements which deflect independently and do not share loads with neighbors. Figure 5.10 illustrates this situation for the Cat 988. Figure 5.11 is a graphical representation of this situation for the HS 20-44 loading.

When mobile truck cranes are engaged in lifting operations, they are stabilized by outriggers which resist overturning by transferring loads through floats into the deck. These float loads are very high. For instance the maximum float load for a P&H 9150 (150-ton) crane lifting a 75,000-lb 40-ft container at a radius of 43 ft is 221,675 lb. (Ref 5.3). Floats may be as small as 30 in. in diameter; however, 4-ft square floats are optionally available and should be used. It is not customary to design piers for such high loads; instead, the following should be done:

a. Use timber or plywood mats or steel beams to distribute the load.

Figure 5.3. HS 20-44 design load (from References 5.1 and 5.2)

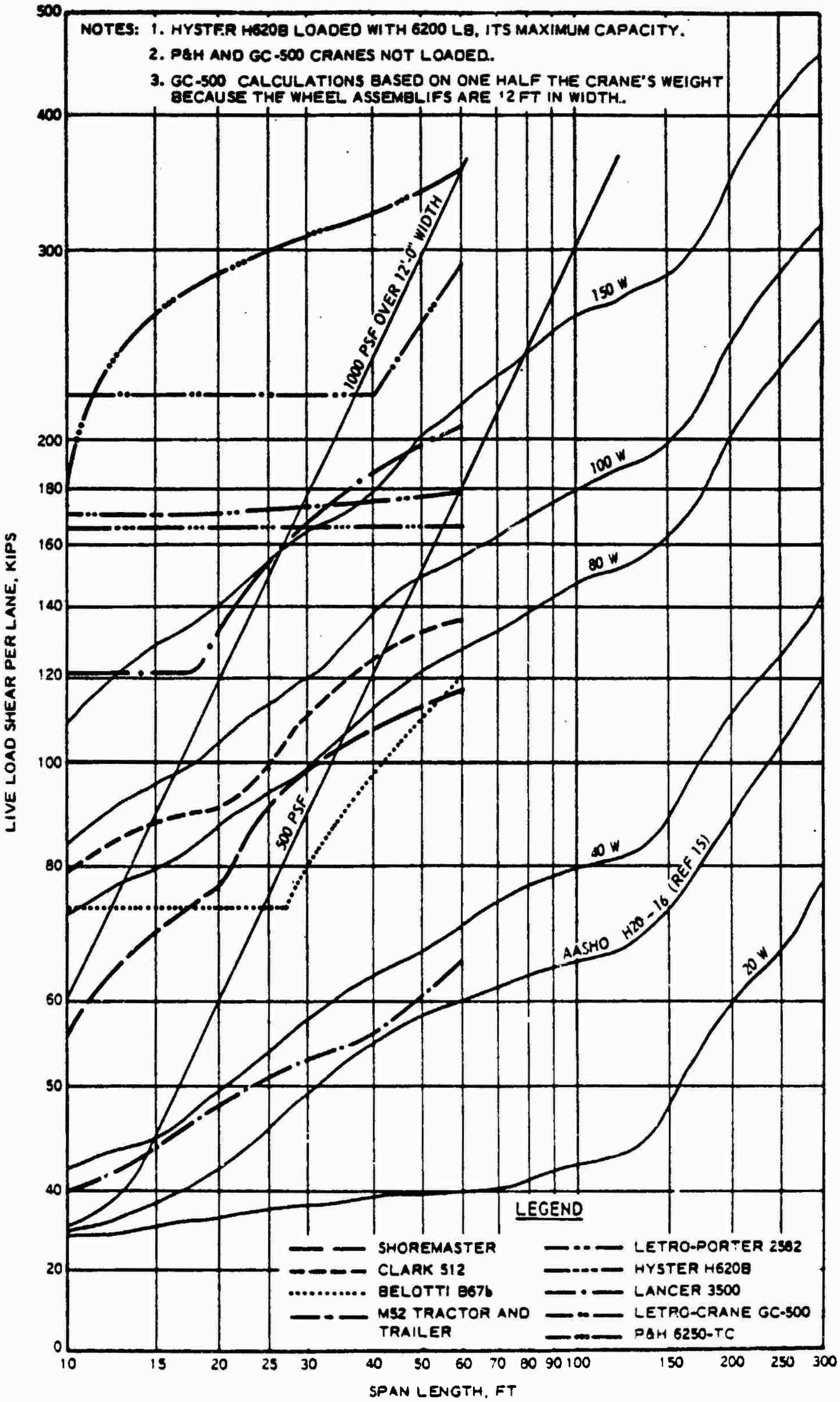


Figure 5.4. Bridge class curves for shear (from Reference 8.7)

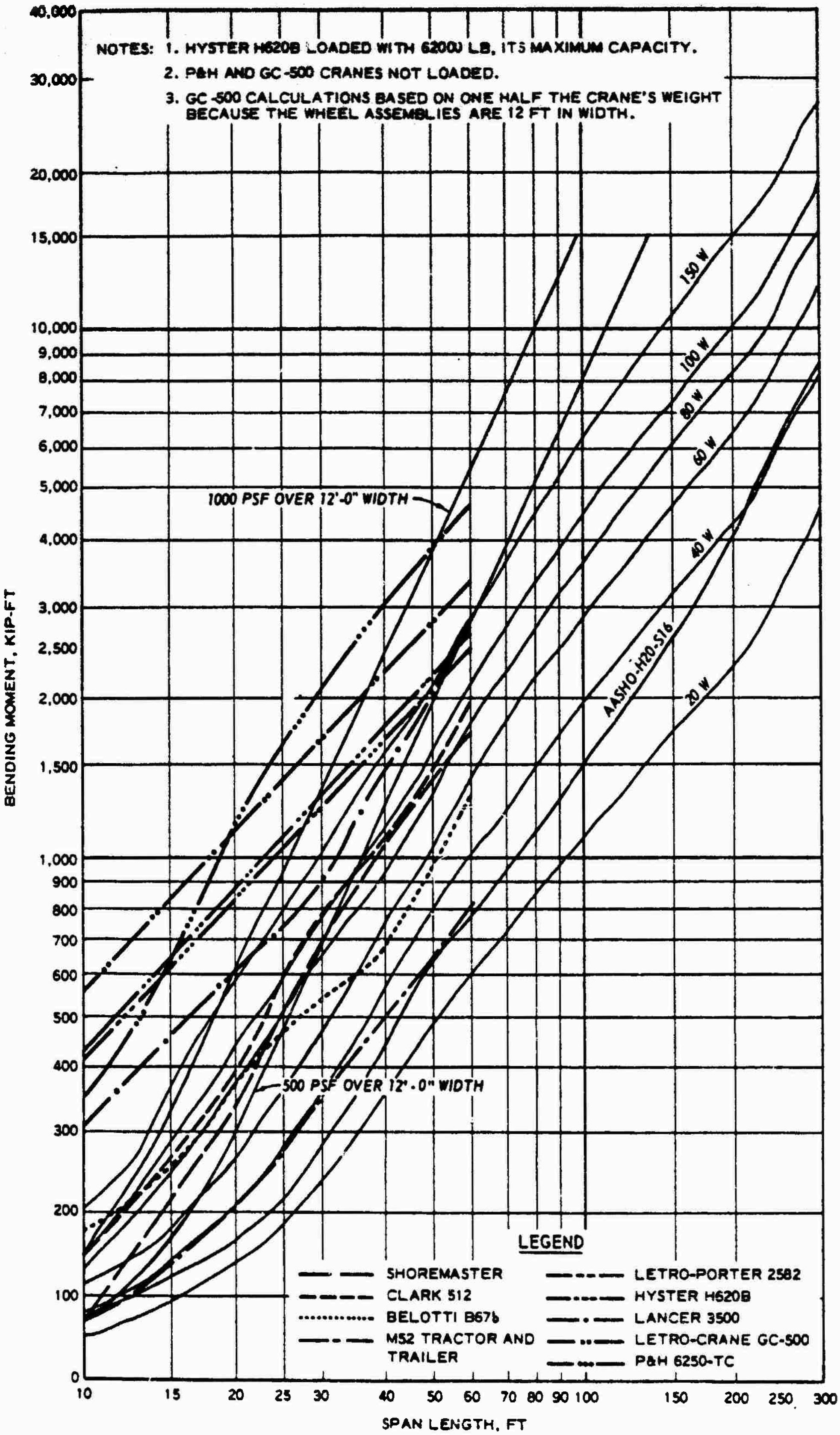


Figure 5.5. Bridge class curves for moment (from Reference 8.7)

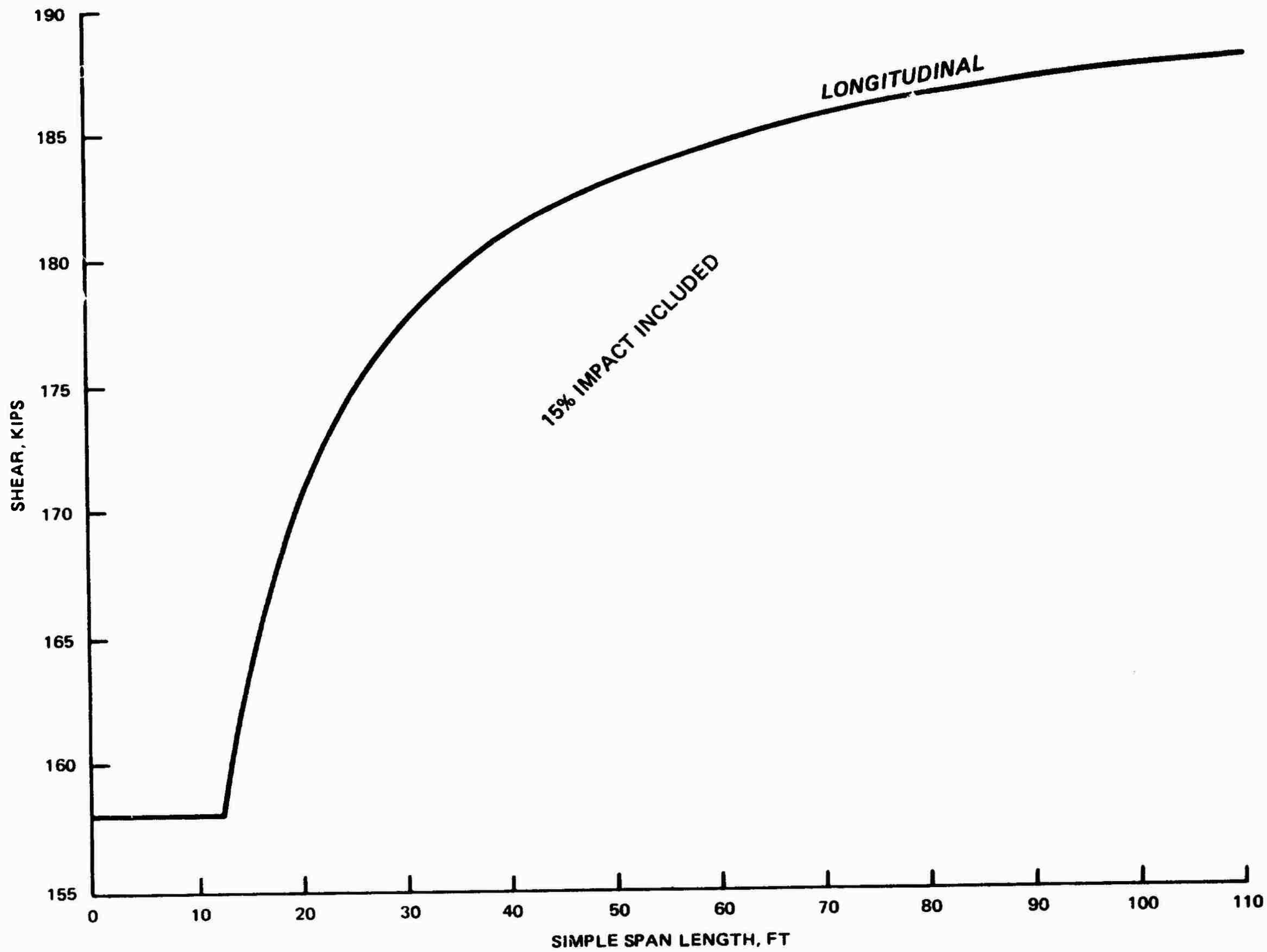


Figure 5.6. Cat 988 shear, 12-ft lane, 15 percent impact factor

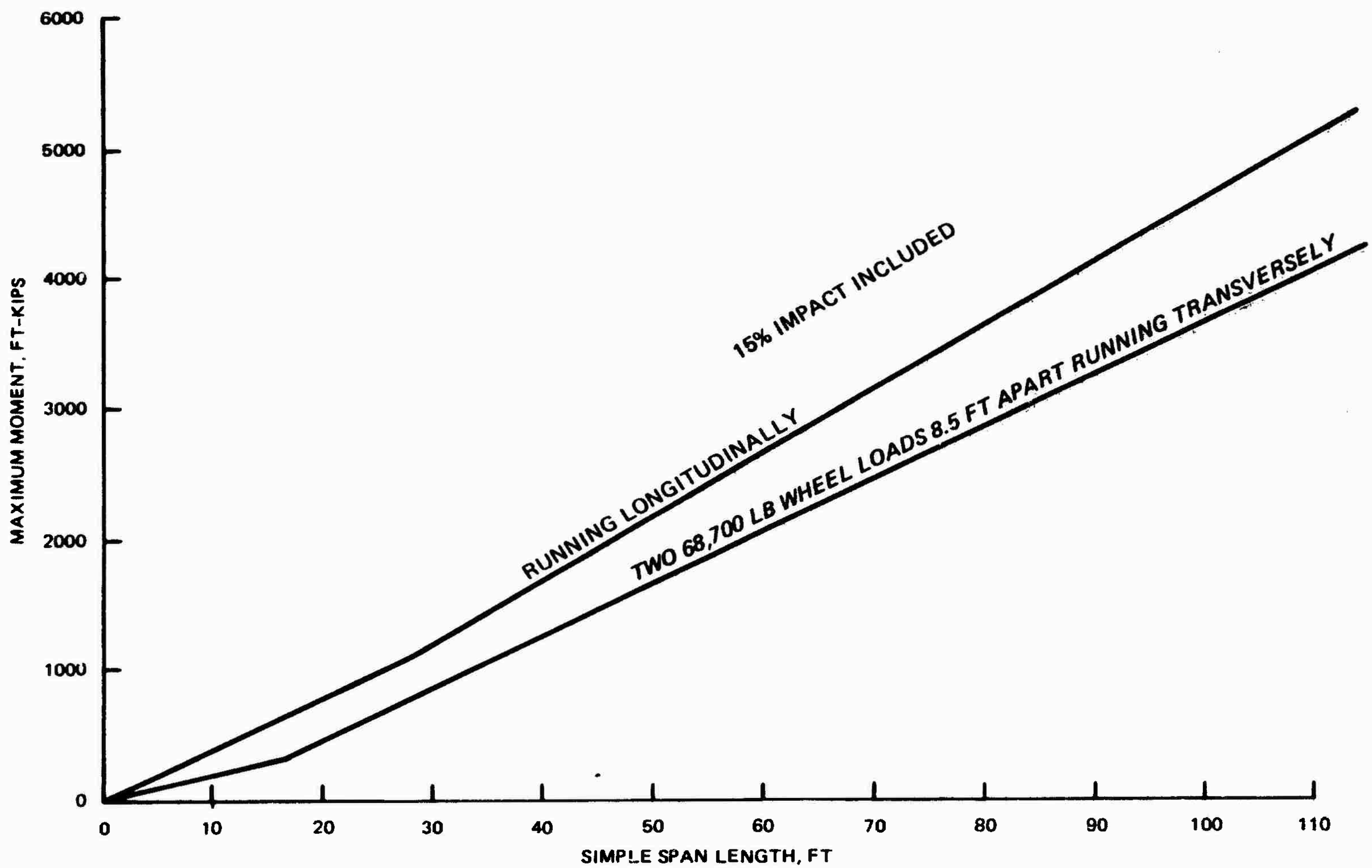


Figure 5.7. Max moment for Cat 988, 12-ft lane, 15 percent impact factor

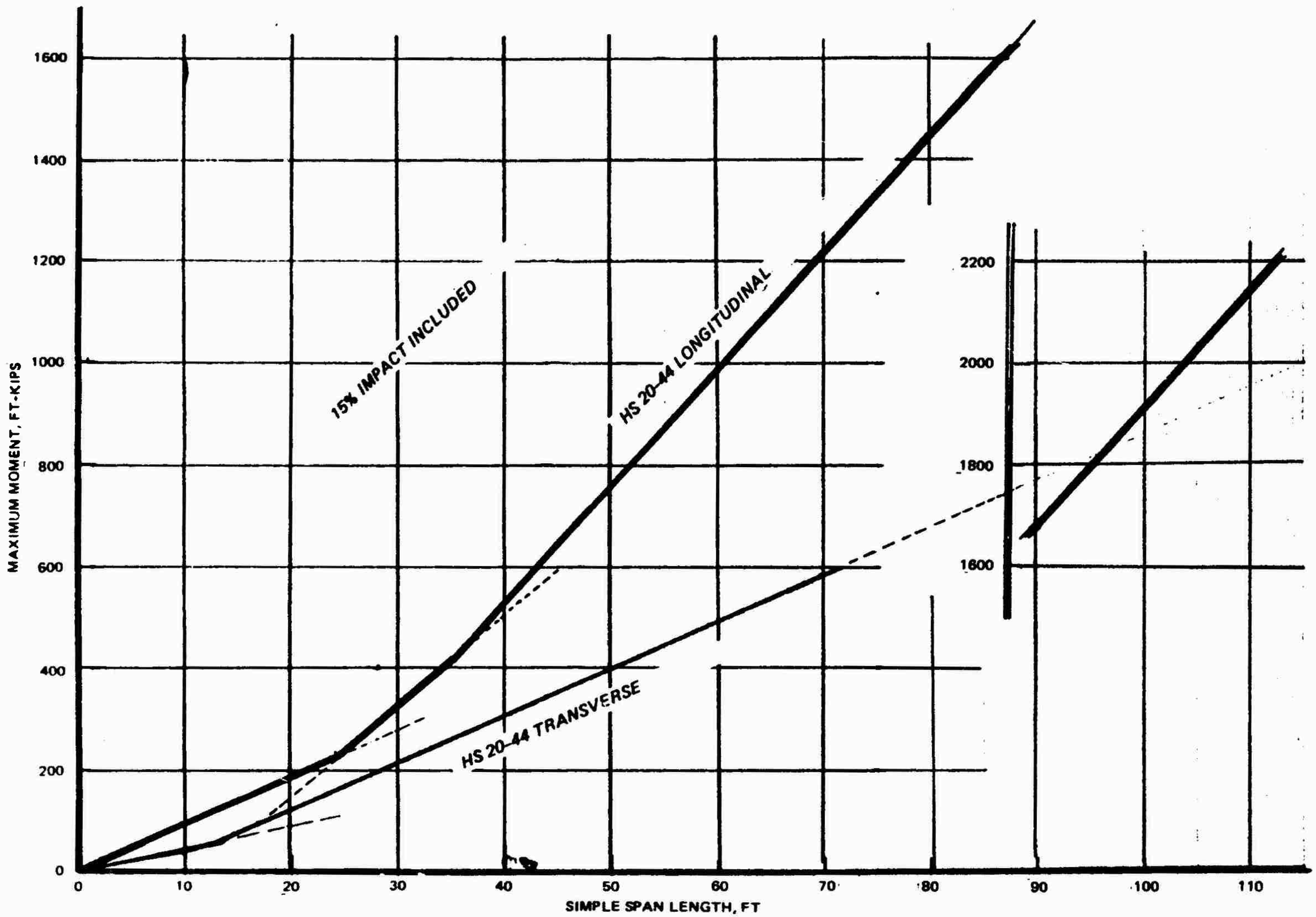


Figure 5.8. HS 20-44 moment, 12-ft lane includes 15 percent impact factor

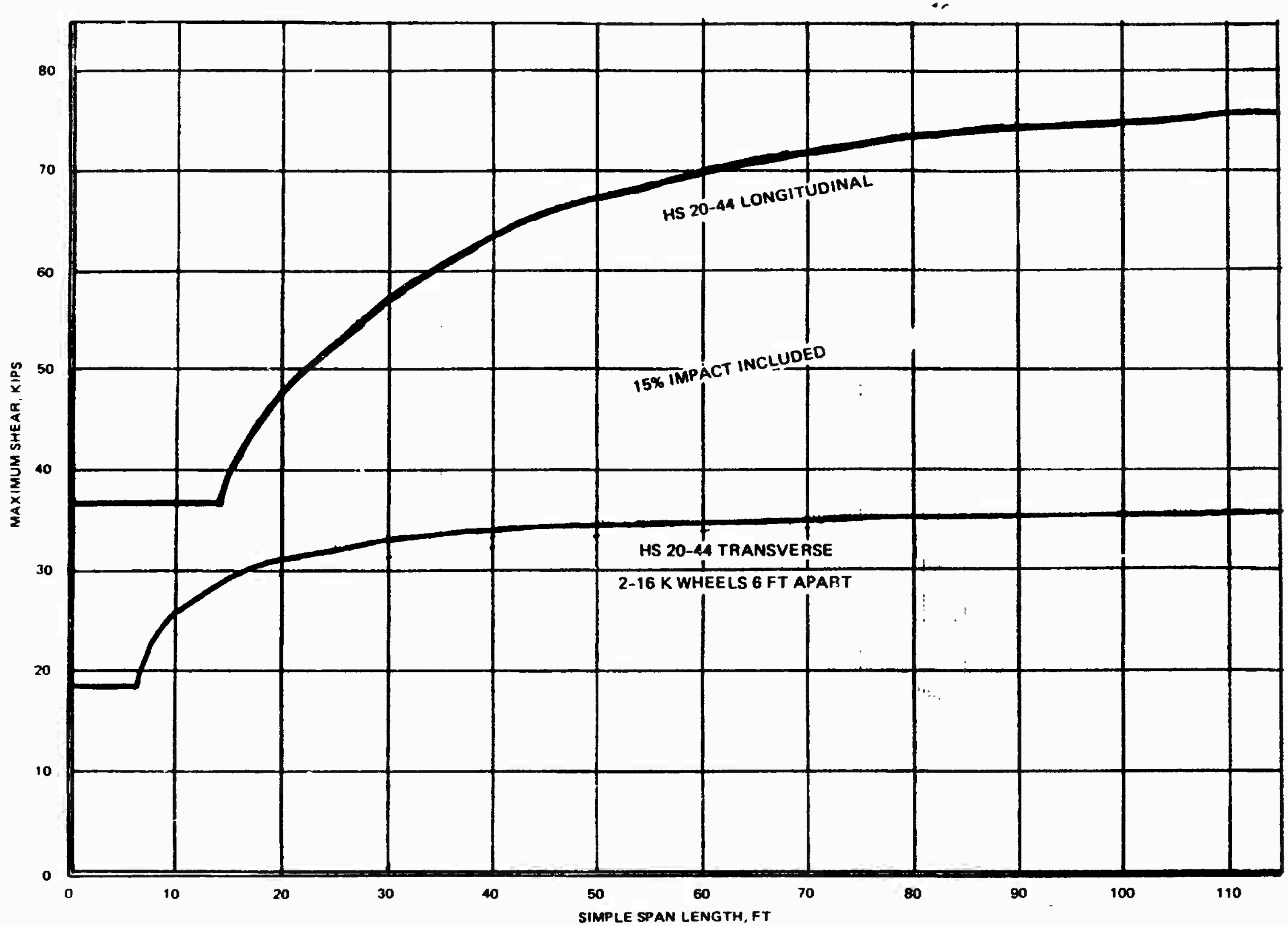
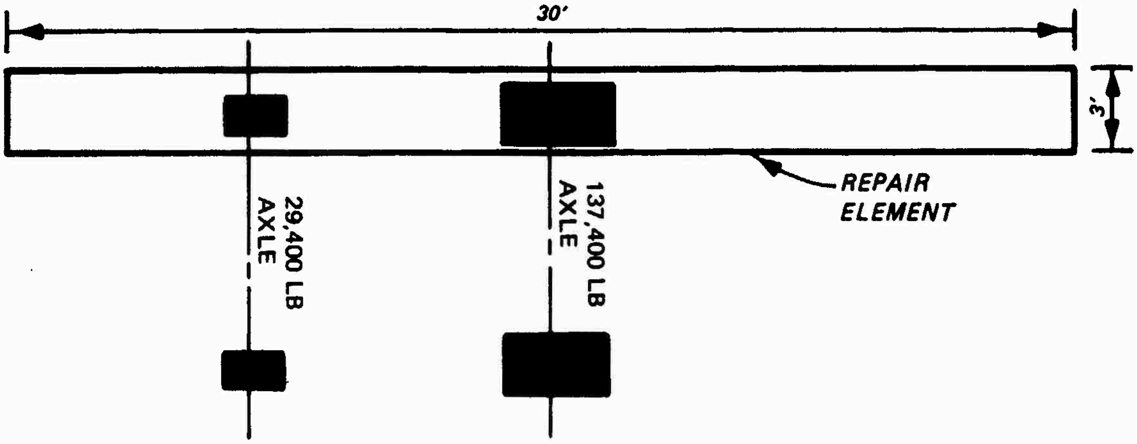
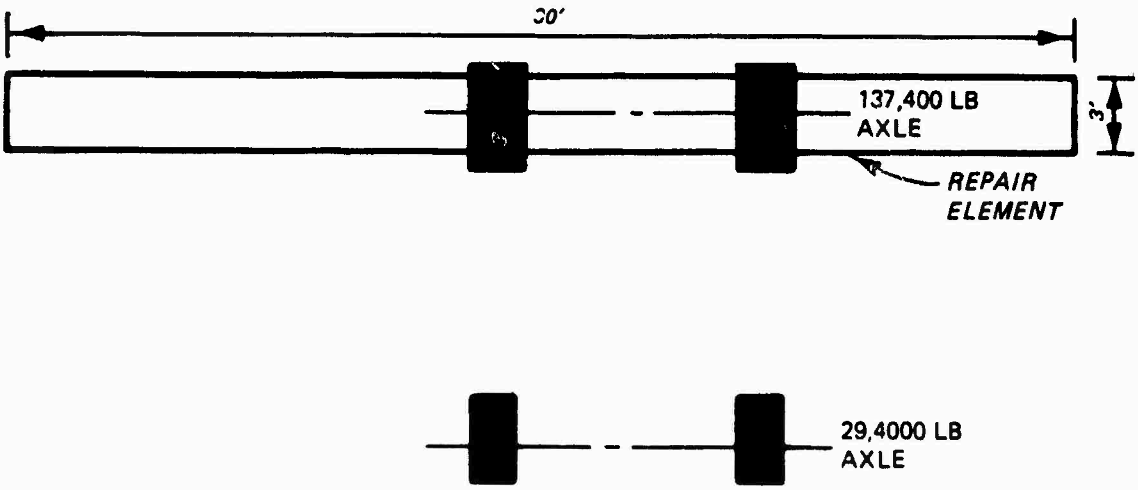


Figure 5.9. HS 20-44 shear, 12-ft lane includes 15 percent impact factor



a. Cat 988 1/2 longitudinal loading,
Max moment demand: 610 ft-kips,
Max shear demand: 88 kips



b. Cat 988 Transverse loading,
Max moment demand: 880 ft-kips,
Max shear demand: 132 kips

Figure 5.10. Comparison of longitudinal and transverse load cases

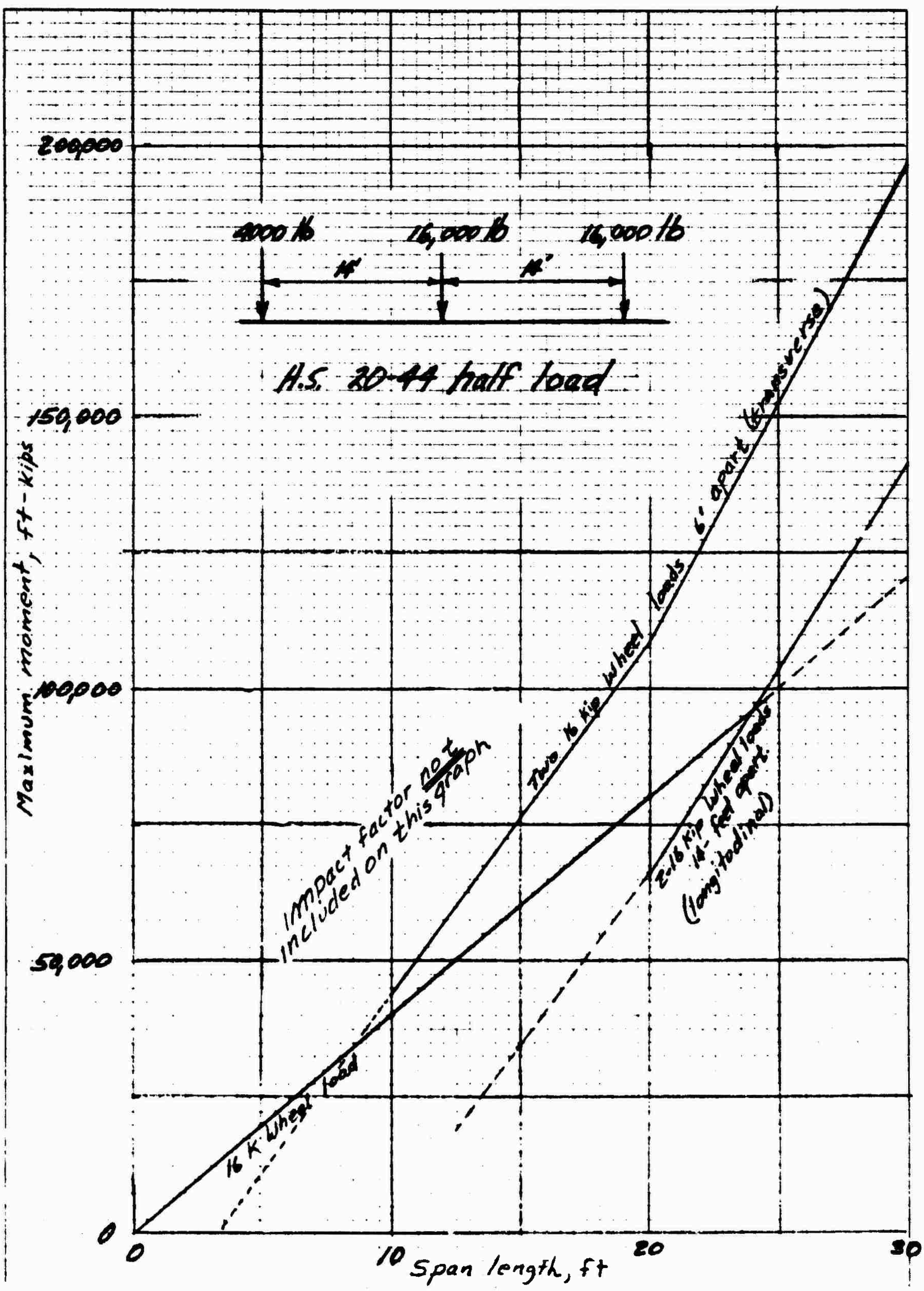


Figure 5.11. Graph comparing longitudinal and transverse load cases for HS 20-44 load

b. Place the floats near rail or tracks in the pier because the pier is usually strengthened to accommodate rail traffic.

c. Place the floats over pier bents, if possible.

d. Locate strengthened areas of the deck and place the floats over these areas.

More information on this subject can be found in Reference 5.3.

6.0 Use and Repair of Damaged Structures

Section 6.1 investigates the load capacity of generic port structures. This investigation was required to determine appropriate load capacity for repairs. There is no need to make repairs which are stronger than the undamaged structure. The investigation into capacity reduction is required because the load capacity of the structure may be reduced in areas adjacent to obvious damage. The engineer must consider this possibility as he plans his repairs.

The remainder of this section includes concrete removal, concrete sawing, concrete drilling, and attachment of steel to concrete and substructure interface. Understanding of these topics will be helpful when the design of specific repairs is discussed.

6.1 Investigation of the Load Capacity of Generic Structures

The results of the load capacity investigation are shown in Table 6.1. The only pier which is suitable for use with all container handling vehicles is Pier 10 at the Norfolk Naval Station. This pier is one of the latest Navy designs. Placement and operation of a 70-ton truck crane is allowed at any location on the pier. It is unusual for a pier to be designed this way because the outrigger float loads are very high. Construction of Pier 10 was not complete when the report was written.

Conventional piers make use of rail-mounted cranes, ship-mounted cranes, or barge-mounted cranes to provide lifting capability. When these methods are used, crane loads are not supported by the deck. Containers are moved by semitrailer trucks so that the HS 20-44 or 1,000-lb/sq ft uniform load criteria will control deck design. The Norfolk International Container Terminal wharf is a good example; the HS 20-44 loading and 1,000-lb/sq ft dead load are the only load criteria met.

Table 6.1 Design Strength of Generic Wharves

Design Load		Norfolk International Container Terminal	Norfolk Naval Station Pier 7	Norfolk Naval Station Pier 10
1,000 lb/sq ft		Yes	Yes	Yes
HS 20-44		Yes	Yes	Yes
Cat 988 Forklift		No	No	Yes
80-Ton Crane		No	No	Yes*
140-Ton Crane		No	No	Yes*
250-Ton Crane		No	No	Yes*
Span Length		20 ft	12 ft	18 ft
Design		one-way precast	two way	one way
Max Allowable Moment	At Support	-58 ft-k/ft	-2 ft-k/ft	-69.8 ft-k/ft
	Midspan	45.5 ft-k/ft	6 ft-k/ft	72.9 ft-k/ft
Max Cantilever length at full capacity		7 ft	4 ft	10.9 ft

* Design strength is sufficient for movement of the crane between setup points. Outrigger float loads may exceed deck capacity. Since outriggers must be extended during operation, floats should be placed in areas of high strength or loads spreading devices should be used.

6.2 Extent of Capacity Reduction Due to Damage

If a pier is damaged, undamaged portions of the pier may suffer a capacity reduction because of loss of support caused by adjacent damage. Consider a direct hit on a one-way slab at pile cap as shown in Figure 6.1. In one-way slab design the main reinforcement runs in one direction; in pier design this is usually perpendicular to the pile caps. Capacity is reduced in the undamaged portions of the span adjacent to the hole because one reinforcement path between the load and support is severed. A conservative method for estimating capacity is to assume that the remaining deck acts as a cantilever extending from the remaining support. Each generic structure was analyzed using this method. The cantilever length tabulated in Table 6.1 is

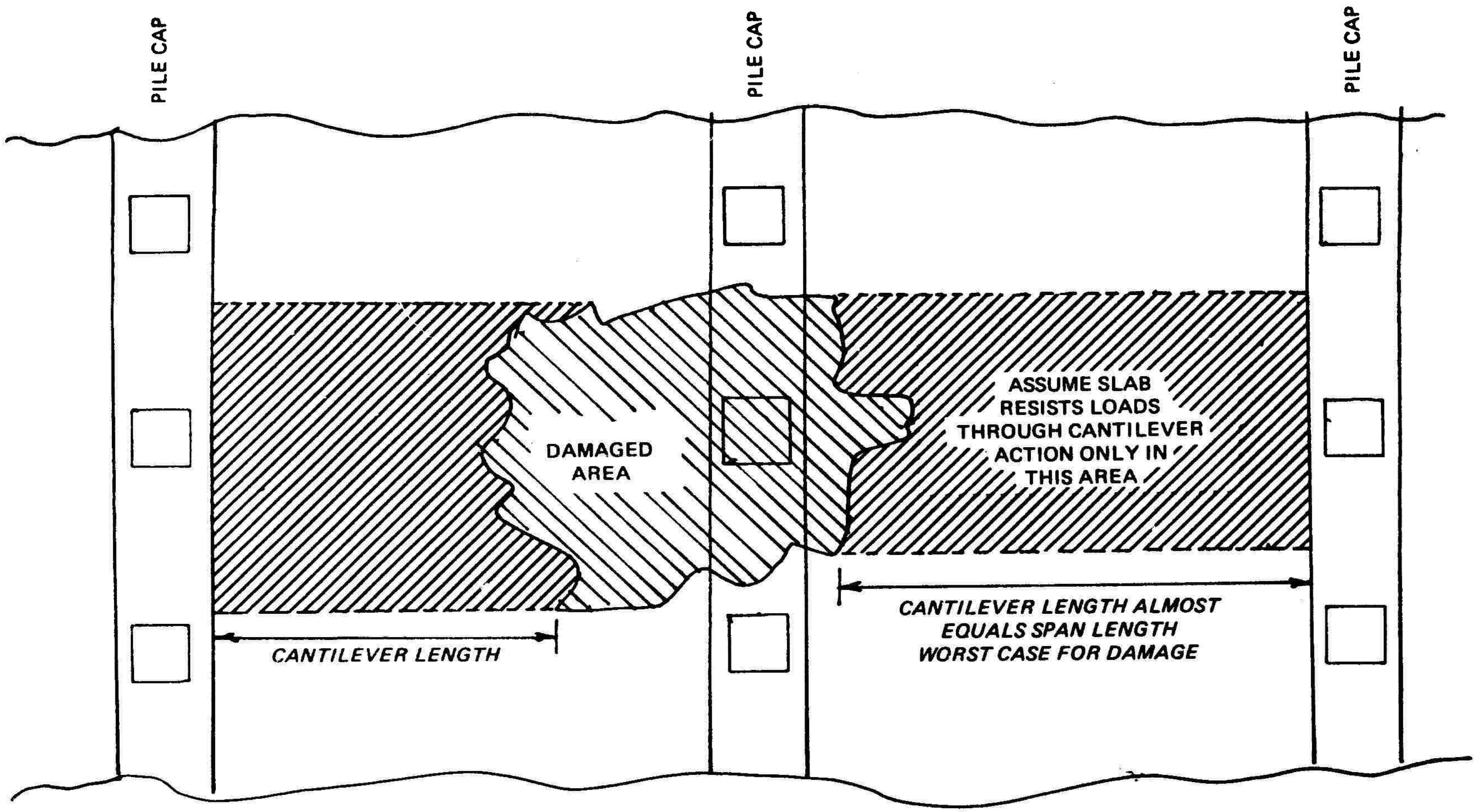


Figure 6.1. Assumed worst case of bomb damage

the distance from the support where cantilever strength becomes less than beam strength.

The foregoing estimate is conservative because it ignores the support that the reduced-capacity area receives from undamaged portions of the deck. Analysis of this extra support effect is difficult and the results would change depending on the size of the damaged area, thickness of concrete, and type of reinforcing used. Estimates using the cantilever method will be sufficient for field use. If necessary, the engineer could check questionable areas by load testing them with rubble.

Since Pier 7 of Norfolk Naval Station is a two-way slab, its capacity in one-way action was considered in cases where reinforcing in one of the directions was severed. Calculations showed that cantilever action from the nearest girder was more effective in supporting loads than one-way slab action.

If repairs are made to damaged areas, consideration should be given to extending the repair past the region of reduced capacity. Figure 6.2 is an example of how underslung steel beams, which are used to support a temporary timber deck, might be extended to support a reduced capacity area.

6.3 Removal of Damaged Concrete

When making expedient repairs, it may be helpful to saw damaged or weakened concrete in order to make way for repairs. The deck may be trimmed to allow prefabricated modules to be set flush with the top surface of the deck (see Figure 3.2).

Several different sizes and types of saws are available. They range from hand-held types for small jobs and restricted areas to large self-propelled ones with 65-hp engines. Wall saws are available which run vertically on tracks to cut door openings in concrete and masonry walls. Saws which may be pushed by one man are used for small jobs on concrete floors and decks. Further information on saws and accessories is available in Reference 6.1.

Several factors impact the productivity of concrete sawing. They include concrete thickness, aggregate type, reinforcing density, size and type of blade, type of saw, length of cut, and amount of maneuvering time required.

A 36-in. blade is required to saw a 12-in.-thick deck. It is difficult to saw a straight line with a 36-in. blade unless it is guided. Highway

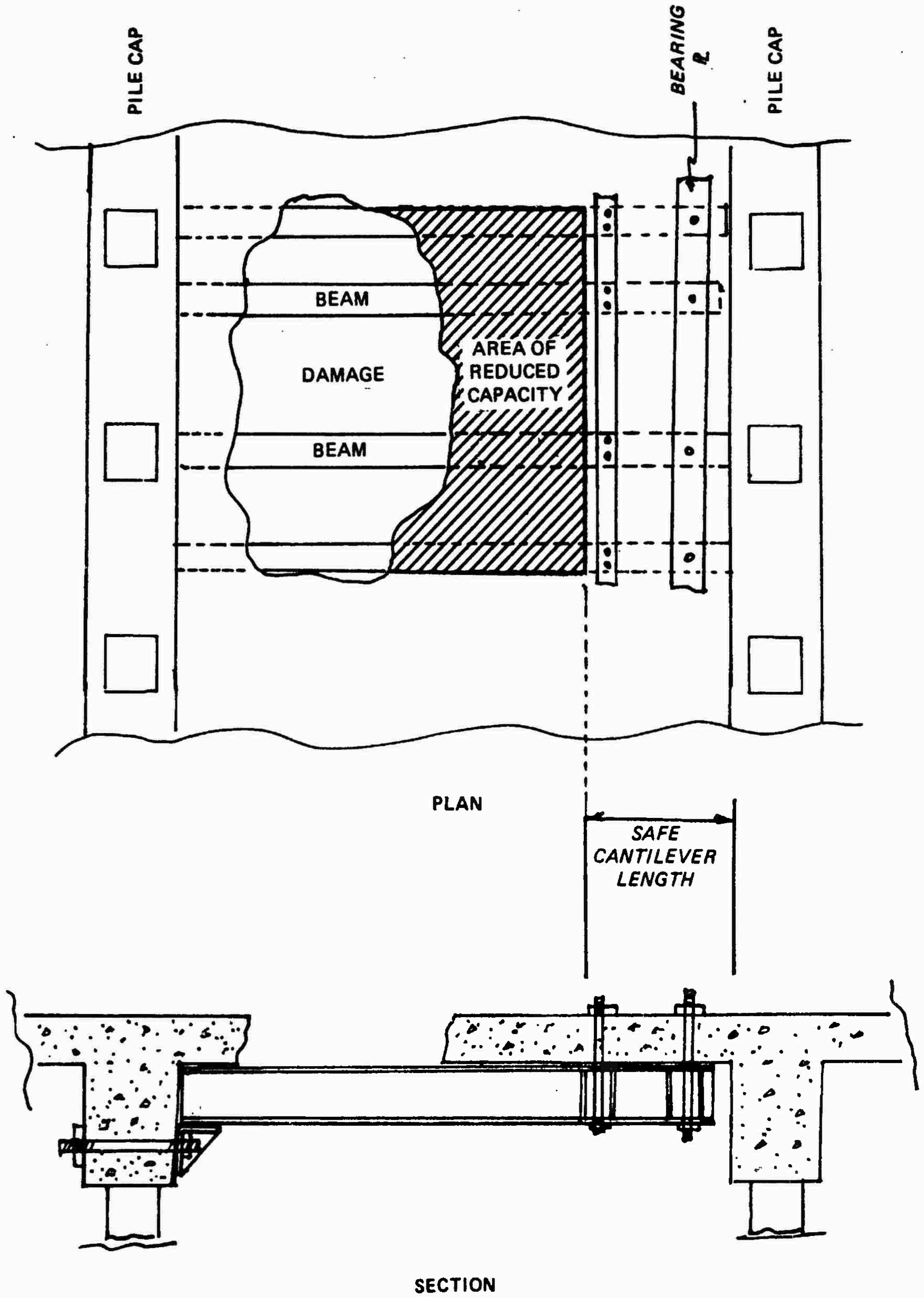


Figure 6.2. Attachment of underslung beams to support weakened areas of the deck

contractors often saw thick concrete in several passes. Twelve-inch concrete is often sawn in three passes, each 4 in. deep. Productive cutting time will be reduced by the time required to change blades. On large jobs, contractors remedy this problem by having three saws follow each other, each cutting at a different depth.

Production varies greatly depending on the type of aggregate embedded in the concrete. Soft aggregates, such as limestone, can be cut quickly. Hard aggregates such as granite, river gravel, and chert are more difficult to cut. Blade life is reduced drastically when cutting hard aggregate; however, proper blade selection will mitigate this problem. The presence of reinforcing also slows cutting and reduces blade life. If a saw cut falls longitudinally on top of a rebar, the cut will have to be abandoned because the cost in lost blade life and time is too great.

Long, straight cuts improve productivity. Although it is possible to maneuver a large highway saw as required to make 12-ft-long transverse cuts on highway slabs, time is lost as the blade is extended and retracted and the machine is positioned.

The movement of concrete which causes pinching and binding of the blade is another source of trouble. Movement may be the result of heating in the summer or stresses caused by settlements and frozen expansion joints. Damaged portions of the deck may require temporary support during sawing in order to reduce blade pinching.

Contractors doing highway work are able to cut 12-in.-thick concrete at a rate of 400 ft/day using one man and one saw. There are wide variations in the actual daily production depending on the previously mentioned factors. Reference 6.1 reports that a daily production of 40 ft/day was accomplished despite extremely unfavorable working conditions. For expedient repair purposes, planners may estimate production between 100 and 200 ft/day for a 12-in.-thick reinforced concrete deck.

The 7-ft-diam carbide cutters are also available. The machinery rides on tracks and looks similar to a large "ditch witch" machine. The machine makes a cut 4 in. wide, and manuf.ctures claim that 120 ft/hr can be sawn. A construction contractor that uses the machines for bridge demolition reports that 60 to 80 ft/hour is a reasonable estimate including moving, setup, and maintenance.

Hydraulic pavement breakers may be mounted on a digging machine in place of a backhoe bucket (Ref 6.2). The production from this unit is at least five times that of a man using a 90-lb breaker. The machine may be used to break deck slabs into blocks by punching a line of closely spaced holes. A highly experienced operator can clean concrete from a steel beam using this machine. Unless these machines are well-maintained and expertly operated, they break down frequently. The 497th Engineer Company has a pavement breaker but avoids using it because of maintenance problems.

A recent development in concrete demolition is the whip hammer. This device consists of chains which are attached to a wheel and flailed at high speeds. It is most effective on salt-damaged concrete bridge decks. An advantage is that it removes the concrete without damaging the reinforcing. The old reinforcing may be reused to splice into a new concrete patch. This machine was first used by Mergentime Corporation of Flemington, N.J., on bridge rehabilitation projects.

Small concrete removal areas and cleanup work may be done with jackhammers. Various sources place the daily output per person at less than 1 cu yd/day. Output may be higher for short jobs before operator fatigue sets in. Work may be assisted with the use of hydraulic splitters or chemicals which are poured into predrilled holes and allowed to expand (Ref 6.3).

Explosives might also be used for concrete demolition. This subject was not researched because ample information on explosives is available in Army literature.

One possible approach for concrete removal is as follows:

a. Saw cut to partial depth the entire perimeter of the weakened area of the deck.

b. On another pass, saw cut to full depth as much of the perimeter as possible without causing movement of the damaged portion which will bind the saw blade.

c. Finish the job with a backhoe-mounted hydraulic pavement breaker.

The time required to cut an opening in a 12-in.-thick deck which will accept a 16- by 40-ft repair module is one 10-hr day. A crew of three or four men would be required: 30 to 40 manhours would be consumed, and 10 hr of schedule time would be used.

6.4 Attachment of Repairs to Concrete

A standard method of attaching repairs to concrete should be developed for use by PCC's. The possible alternatives are illustrated in Figure 6.3. The necessary materials should be included with material shipped to the TO.

Most underslung beams may be supported by core drilling holes through the deck and inserting bolts. High strength (A325) bolts 1-1/2 in. in diameter will provide a tensile strength of 70 kips according to the AISC steel manual. This strength is sufficient, and a few bolts could support container vehicle loads. Bearing plates should be provided on top to spread the load from the bolts across the deck (see Appendix D). The beams may need reinforcement at the connection to resist concentrated stresses.

Based on information from Reference 8.3, one man can core drill at least eight holes of 2 in. diam through a 12-in.-thick deck in a 10-hr day.

Anchors, which can be drilled into existing concrete, come in two forms. Mechanical anchors are bolts which are driven into tightly fitting holes which have been predrilled. A nut and washer is threaded onto the exposed end of the bolt and tightened until it comes in contact with the concrete surface and starts to pull the bolt out of the hole. Friction inside the hole engages wedge anchors which prevent the bolt from being pulled out.

Epoxies and other resins may also be used to secure bolts into predrilled holes (Ref 6.4 and 6.5). Some epoxies may be poured into vertical holes which are open from above. Paper or glass capsules may be used to retain epoxy in horizontal holes before inserting the bolt.

About 1-in.-diam anchor bolts have sufficient shear strength for most uses contemplated in this study. A sample data sheet for wedge anchors is shown in Figure 6.4.

6.5 Substructure Interface

In some cases, deck repairs will be supported by substructure elements such as piling. In other cases the repair is supported by the undamaged deck or the pile caps.

A parallel effort was undertaken to determine expedient repair procedures for damage that occurs below the waterline (Ref 6.6). Results from this study indicate that deck repairs would be supported by various columns which are

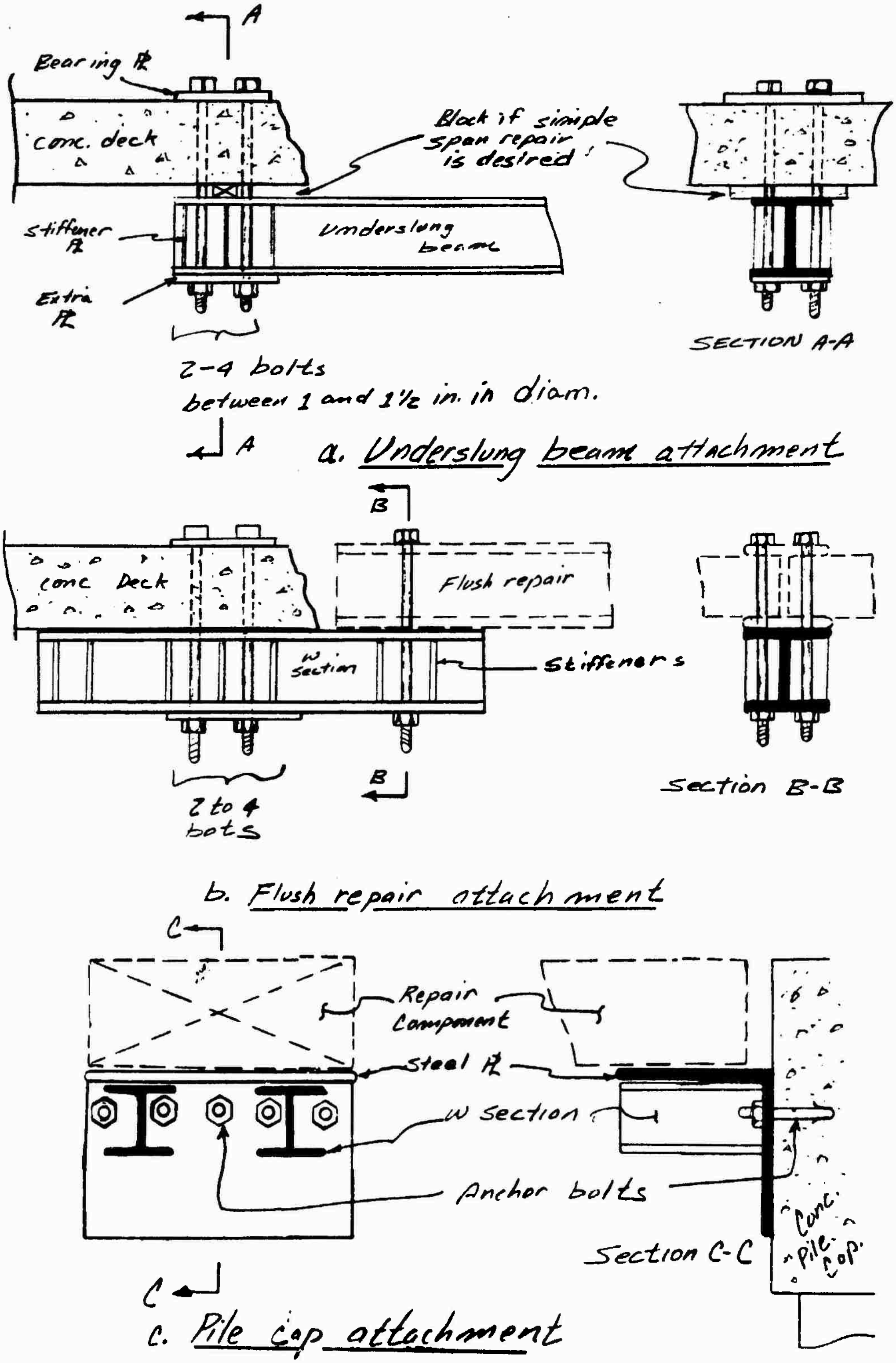
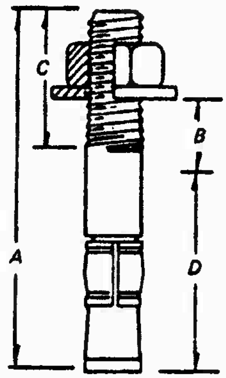


Figure 6.3. Proposed methods to support repairs from undamaged parts of the structure



WEDGE ANCHOR

ANCHOR DIA AND DRILL SIZE, IN.	A OVERALL LENGTH, IN.	B MAX THICK OF MATL, IN.	C THREAD LENGTH, IN.	D MIN EMBED-MENT IN CONCRETE, IN.	ULTIMATE *PULLOUT, LB	ULTIMATE *SHEAR, LB
1/4	1-3/4 2-1/4 3-1/4	3/8 7/8 1-7/8	3/4 3/4 3/4	1-1/8	1,346	2,161
3/8	2-1/4 2-3/4 3 3-3/4 5	3/8 7/8 1-1/8 1-7/8 3-1/8	1-1/8 1-1/8 1-1/8 1-1/8 1-1/8	1-1/2	3,250	4,031
1/2	2-3/4 3-3/4 4-1/4 5-1/2 7	1/8 1-1/8 1-1/2 2-3/4 4-1/4	1-5/18 1-5/18 1-5/18 1-5/18 1-5/18	2-1/4	5,084	6,547
5/8	3-1/2 4-1/2 5 8 7 8-1/2	1/8 1-1/8 1-5/8 2-5/8 3-5/8 5-1/8	1-3/4 1-3/4 1-3/4 1-3/4 1-3/4 1-3/4	2-3/4	7,744	11,984
3/4	4-3/4 5-1/2 7 8-1/2 10 12	3/4 1-1/2 3 4-1/2 6 8	1-3/4 1-3/4 1-3/4 1-3/4 1-3/4 5	3-1/4	9,355	16,013
7/8	8 8 10	1-3/8 3-3/8 5-3/8	2-1/2 2-1/2 2-1/2	3-3/4	13,448	20,881
1	6 9 12	1/2 3-1/2 6-1/2	2-1/2 2-1/2 2-1/2	4-1/2	19,234	35,778
1-1/4	9 12	2-1/4 5-1/4	3-1/2 3-1/2	5-1/2	23,568	38 968

* ULTIMATE LOAD CAPACITY IN 4090 PSI, 3/4 IN. CRUSHED LIMESTONE AGGREGATE CONCRETE.

Figure 6.4. Sample data sheet for wedge anchors

quite similar to piling. It is recommended that the deck repairs rest on top of the column after it has been cut off to the proper elevation. A loosely fitting collar should surround the top of the pile. The collar should not allow horizontal movement between the column and the repair, and it should not transfer moment from the deck repair to the column. This is because the addition of moment to the column greatly reduces its capacity because of the possibility of elastic buckling. If the column frame is attached to the bottom of a steel beam, web stiffeners should be attached to the beam at the column location to prevent buckling of the web.

The umbrella concept, which is illustrated in Figure 6.5, involves driving a pile in the center of a crater and then covering it with a cap which is trimmed to fit the crater. It was assumed that concrete would be the material of choice for the cover. The steel plate and erector set concepts explained in Sections 8.2 and 8.3 could also be used to provide an umbrella cover. Bolt holes would be available to attach a collar which could be made from steel angle. The column could frame into a transverse beam which would act as a pile cap and spread the support across the repair (see Figure 6.6).

In some cases, it may be most effective to bridge over damaged piling by providing a stronger deck material. If this is done, consideration should be given to the extra load that will be placed on undamaged piling. If there is insufficient reserve capacity, extra bottom support should be provided.

7.0 Requirements for Repair Systems

7.1 General Requirements

A repair system which is designed for military use should have the following attributes:

- a. Versatility. The components may be used to affect a variety of repairs.
- b. Compact for shipping. Saving cubage is more important than saving tonnage on most sealifts.
- c. Components or modules of the repair system should be stored in container compatible racks. The maximum lifting weight should be about 40,000 lb. This is less than the maximum weight for a 20-ft military container. Maximum container weights are 44,800 lb for a 20-ft container and 67,200 lb for a 40-ft container (Ref 7.1).

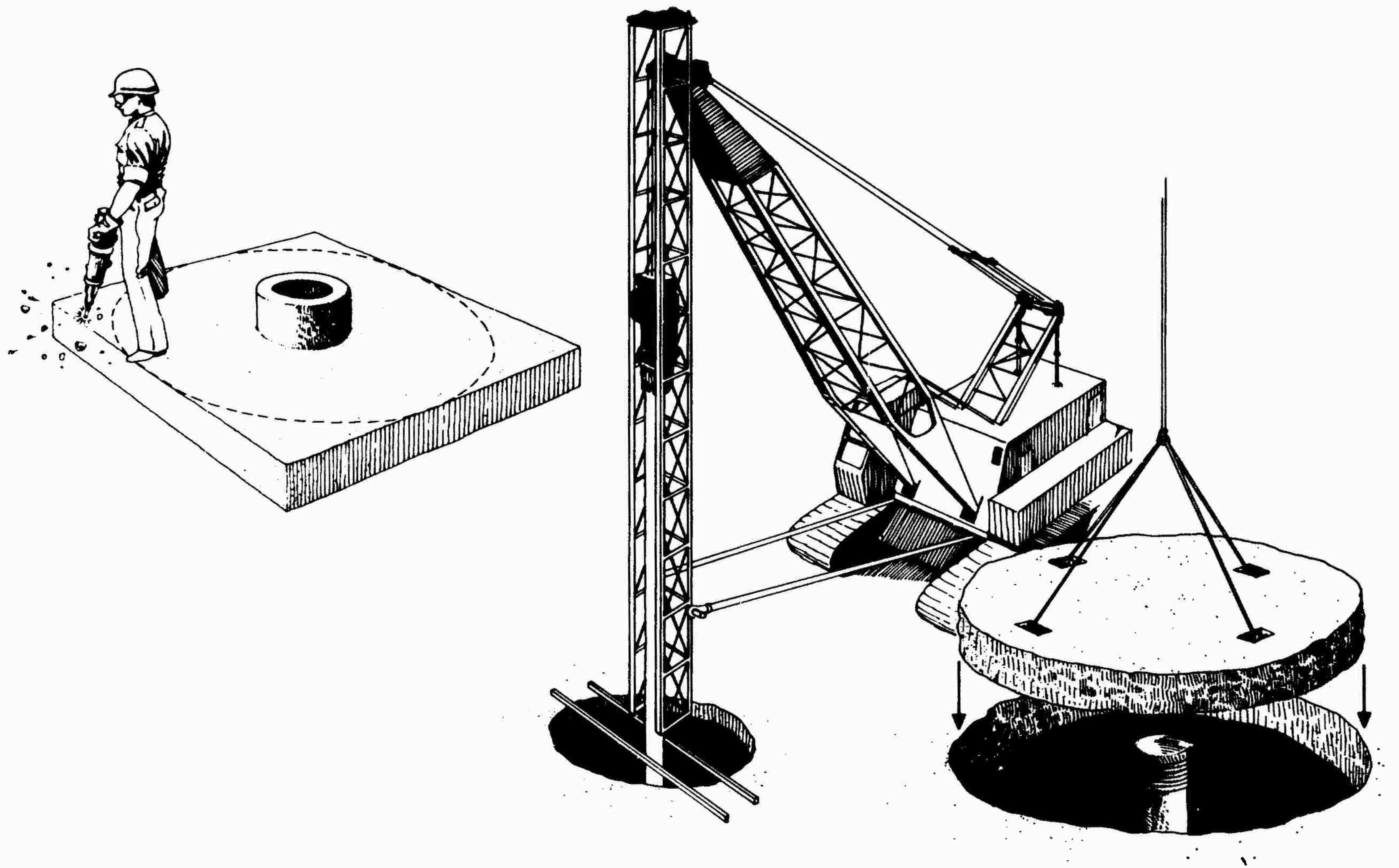


Figure 6.5. Umbrella concept

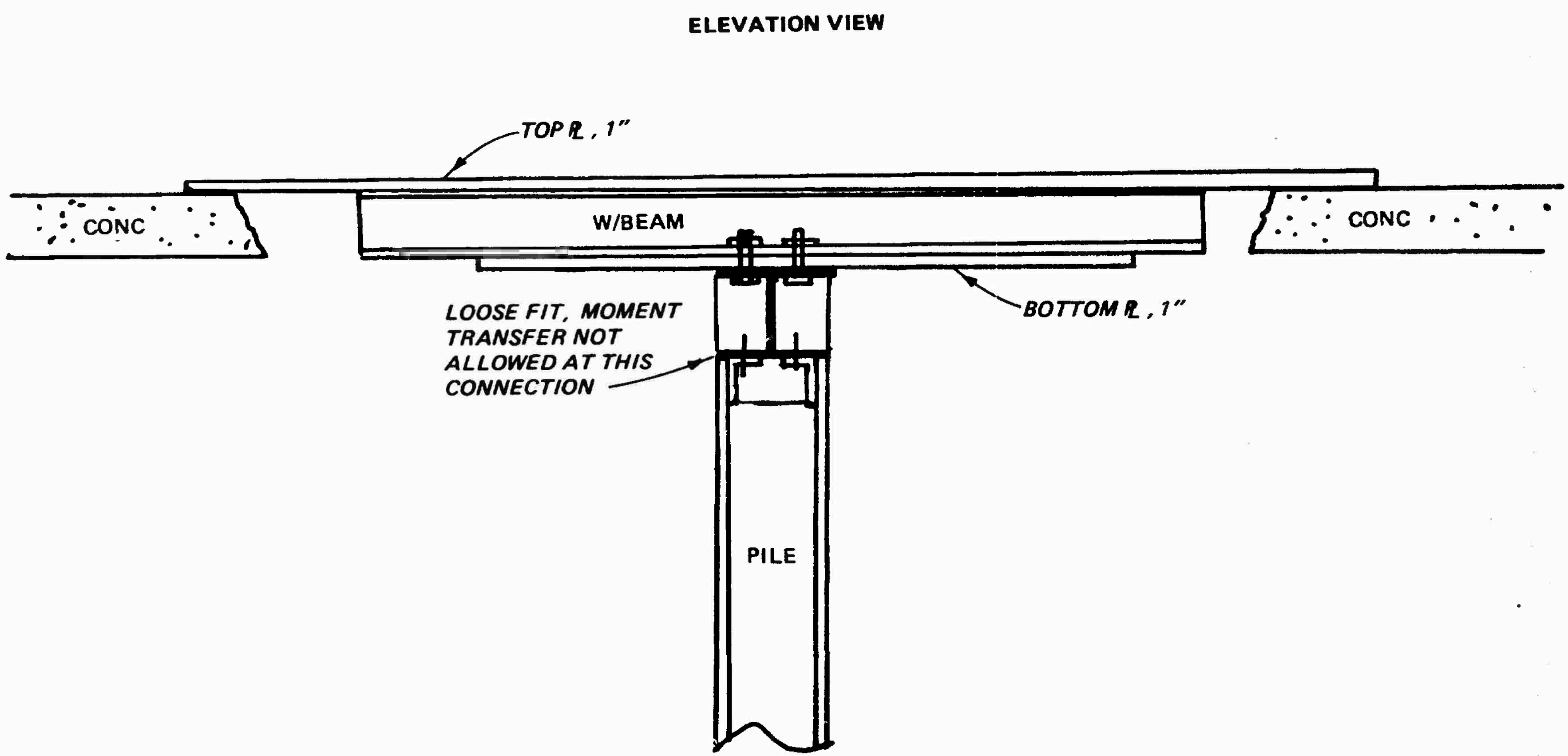


Figure 6.6. Use of steel components for the umbrella concept

d. Assembly should be a low technology operation which can be done with hand tools and indigenous labor if necessary.

e. The repair should show visible signs of distress long before failure. Sudden catastrophic failure modes should be avoided.

f. Minimum time should be required to prepare the damaged area for repair.

g. A minimum of different components should be required to assemble the repair system.

h. The repair system should be much stronger than previously developed systems because of the high demands of modern container handling equipment.

i. Repairs should be available to bridge up to 40 ft. This is because it might be necessary to bridge over a pile bent. Pile bents are typically spaced at 20 ft on most open piers.

j. Designs must accommodate maximum container loads on an occasional basis. Most containers are loaded below their maximum limit. Ammunition containers are close to the maximum weight limit.

It is recommended that a primary repair system be developed which uses 2-in. high-strength steel plates to cover small holes and uses various combinations of steel plates and beams to bridge large damaged areas. Steel was chosen because of the high structural resistance and low shipping cubage required. Availability is high and shop fabrication and field modification can be accomplished using proven technology. Components of the repair system will fit into 8- by 8- by 40-ft modules or 8- by 8- by 20-ft modules which will stack 8 ft high for convenient shipment with containerized cargo. The repair system may also be prepositioned and preassembled for use at a specific port. The components would be purchased and fabricated in peacetime and held ready for future use.

Development of concepts which use timber, concrete, steel bar grate, and railroad cars is also recommended. If these materials are available within the TO, a sealift would not be necessary. If timber and bar grate were sealifted to the TO, greater shipping cubage would be required in comparison to steel plate and beams. If the supply of steel is exhausted, the shipment of timber may be necessary.

7.2 Material Requirements for Steel

Since the primary material recommended for repairs is steel, it is appropriate to discuss the selection of types of steel. High yield strength

is desirable to provide structural resistance with little weight. High ductility allows steel to undergo large post-yield elongations before ultimate failure. This allows redistribution of stresses away from stress concentrations and, in some cases, prevents sudden collapse of a structure.

For an expedient port repair system, high strength, high ductility, machinability, and weldability are important attributes for steel. It is expected that the systems may be assembled without welding; however, it is possible to have weld equipment if available.

The strength of steel is usually reflected by its nominal yield point in kips per square inch. The modulus of elasticity describes the stiffness of the material. This remains the same despite changes in yield strength. A repair made of high grade steel may perform poorly even though it does not fail by yielding; if a repair is not stiff enough, excessive deflections render it useless.

ASTM A36 (36 ksi) steel is the most commonly available. Rolled sections are available in grade 50 ksi material, and plate is available in up to 100 ksi material.

High strength bolts are subject to corrosion and fatigue problems. They may perform satisfactorily for the short design life of expedient repairs, but they should be used with caution.

Generally, any process which increases the strength of steel reduces the ductility. Low temperatures aggravate this problem. Addition of special alloys and a quench and temper process can increase strength while preserving most of the ductility. High grade steel will be more difficult to machine and will require a special welding rod for welding. Reference 7.2 explains special problems associated with high strength steel.

Machining and welding steel which is less than 1 in. thick is quite easy. Machining and welding steel which is greater than 2 in. thick require special procedures and great skill.

For expedient port repair purposes, it is suggested that ASTM A36 steel less than 1 in. thick be used for components which lend themselves to field fabrication. The A36 steel has excellent ductility, machinability, weldability, and availability. If higher strength steel and lighter sections are used, deflection problems may result. High strength steel components up to 2 in. thick may be appropriate if little field modification is necessary. Planners must consider the problems of identifying high strength steels at the

construction site so personnel are aware of its extra load capacity and special fabrication problems.

7.3 Stiffness Requirements for Expedient Repairs

As stated earlier, some deflection in repair components under load is good because it gives a visual indication of distress to the casual observer. If deflections are too large, they can cause problems. Simple analysis procedures used by structural engineers assume that deflections will be small in relation to the span length. If deflections are too large, special analysis is required. Design of supports is troublesome when deflections are large. A simple support must allow for rotation of the repair. If the repair extends beyond the support, the end will lift as the center is depressed. If a load is not centered on a beam member exactly, which is the case when a container handling vehicle drives on the edge of an 8-ft-wide plate, the member will have a tendency to twist. This will be accentuated as deflections became larger. Larger deflections may cause high dynamic loads if the motion of the vehicle excites the natural frequency of the repair. Personnel may be hesitant to use the repair if it appears too flimsy, even though it may be safe from a technical standpoint.

A design criterion which set numerical limitations on deflections which are applicable to an expedient repair situation was not found. The trilateral design and test code for military bridging and gap crossing equipment (Ref 7.3, Section 5.2) restricts allowable deflections as follows:

> Deflections are not limited by this code but must be considered when they cause changes in loading, affect fit or alignment, or affect the use of equipment.

Quantitative limitations on deflections could be determined during test and evaluation of proposed repairs.

7.4 Allowable Material Stresses for Expedient Design

Steel components which were designed under this study were sized using allowable stresses in steel which are in excess of those used for conventional permanent design. The allowed bending stress was set at the yield limit for steel. The allowed shear stress was set at the yield limit divided by 1.5 for

that part of the section which is effective in resisting shear (the web, in the case of a W section). This liberal design policy is justified because of the temporary and expedient nature of the construction and the need to save shipping cubage. Similar allowable stresses are used by designers of temporary structures for construction projects on a regular basis. Maximum loads are experienced on an occasional basis, mostly when ammunition is being handled. Deflections in the structures will give personnel visible signs of distress before failure occurs, and slight distortions in the repair units will not destroy their usefulness.

Allowable stresses in timber are similar to those used in Reference 7.4. Concrete bearing strength is assumed to be 1,000 lb/sq in.

Further research and review of allowable stresses for expedient repair design are recommended. A complete test and evaluation of prototype repair modules will increase safety and highlight critical structural areas.

8.0 Design of Repair Methods

Several different repair methods were developed under this work unit. They are as follows:

a. Steel plate concept.

b. Erector set concept.

c. Steel beam mat concept.

d. Steel beam and timber deck concept.

e. Steel beam and steel bar grate concept.

f. Precast concrete beam concept.

g. Railroad flatcar concept.

These repair methods were applied to a typical damaged berth, and comparisons of required resources were made. The following resources were considered.

a. Schedule time. This is the number of actual hours required to make the repair. It is assumed that necessary materials are stockpiled within 1 mile of the site and that crews will work two 10-hr shifts daily. Activities which involve use of a crane often control schedule time. A crew size of 5 to 10 is assumed.

b. Manhours. This estimate includes crew supervisors who work with the crew and equipment operators. Officers, staff, and support personnel are not included. Estimates are based on information from References 8.1, 8.2, and 8.3. Conversations with contractors and the author's personal experience from past employment in heavy and marine construction were also helpful in making estimates.

c. Shipping cubage. This refers to the volume required for shipment of repair components in container compatible racks. Allowances are made for waste due to cutting and fitting.

d. Shipping weight. This refers to the weight required for shipment of components. Allowances are made for waste due to cutting and fitting. Density of steel is 490 lb/cu ft. Density of wood is estimated at 40 lb/cu ft. Density of concrete is estimated at 155 lb/cu ft.

e. Acquisition cost. This is the cost to acquire repair components in the United States for prepositioning purposes. Prices were determined by inspection of Reference 8.3 and conversations with suppliers and contractors. Baseline unit costs for materials are shown in Table 8.1.

Table 8.1. Baseline Government Acquisition Costs for Materials

Item	Cost $	Unit
ASTM A36 steel, no fabrication required	0.50	lb
ASTM A36 steel, light fabrication required	0.75	lb
ASTM A36 steel, heavy fabrication required	1.00	lb
High strength steel plate	0.75	lb
Steel bar grate, machine made (bars 4 by 3/8 in. or smaller)	1.00	lb
Steel bar grate, hand made (bars 4-1/2 by 1/2 in. or larger)	1.50	lb
12 by 12 in. by 20 ft timber	200	ea
Prestressed concrete beams	425	cu yd

f. Maximum lift weight. This is the maximum weight of a unit that must be lifted in order to complete the repair.

g. Several qualitative items were also compared. They were:

(1) Shop fabrication requirement.

(2) Possibility of assembly in the TO prior to hostilities.

(3) Flush repair capability.

(4) Prepositioning requirement.

(5) Crane requirement.

(6) The possibility of transporting components by dragging them with a large vehicle.

(7) Concrete removal requirements.

The results of the comparisons are tabulated in Section 9.0. This includes comparison of the HS 20-44/1,000 lb/sq ft load and the Cat 988/P&H 6250 TC (250-ton crane) load case. Henceforth, container handling vehicle (CHV) refers to the Cat 988/P&H 6250 TC loading. The steel plate concept was not compared with other methods directly because steel plates are not strong enough to repair all types of damage. Instead, a comparison was made between methods when steel plates were used to repair small damage areas. Repairs using railroad cars are not compared because of limited applications foreseen.

Sections 8.3 through 8.8 are narrative explanations of repair methods. Design and comparison calculations are found in Appendix D.

8.1 Baseline Repair Scenario

A "typical damaged container berth" was developed so comparisons could be drawn between repair methods. The typical berth is similar to the generic piers and wharves (see Table 8.2 and Figure 8.1). The typical damaged container berth closely resembles the NICT because the NICT was the only generic structure specifically designed for container traffic. Repair requirements closely match those of the other piers. The following cases of damage were considered (see Figure 8.2):

a. Case 1. Midspan damage only.

b. Case 2. Midspan and one cantilever damaged or weakened (NAVSTA, Norfolk, Pier 7 and Pier 10) not subject to this damage case (see Figure 8.3).

c. Case 3. One pile cap and midspan areas of adjacent spans weakened or damaged. The pile cap might be bridged over in this case. If any pilings are bridged over, the ability of the remaining piling to take the extra load should be checked.

The usefulness of repair methods for spans up to 40 ft is considered in Appendix D. This is to demonstrate the versatility of the repairs. The safe cantilever refers to that portion of the deck that can be cantilevered out from the pier cap without capacity reduction. The midspan area is the part of the deck that would suffer capacity reduction if support from one of the pier caps was cut off. The damaged areas are considered rectangular. This is because the bomb craters will cut the reinforcing steel which runs at right angles within the deck slab. This results in areas of reduced capacity which

Table 8.2. Comparison of Damage Scenario Between Generic Piers and Typical Berth

Number of Hits	Case 1 3	Case 2 6	Case 3 3 hits, one repair
NICT			
Reduced capacity area	9 by 9 ft	13 by 9 ft	20 by 26 ft
(Deck span 20 ft Deck thickness 12 in. Safe cantilever 7 ft Pile cap span 11 ft)			
P7 NAVSTA			
Reduced capacity area	9 by 9 ft	N/A Any hit which destroys a cantilever but not a pile cap destroys the midspan.	24 by 24 ft
(Deck span 12 ft Deck thickness 8 in. Safe cantilever 4 ft Pile cap span 8 ft)			
P10 NAVSTA			
Reduced capacity area	9 by 9 ft	N/A, safe cantilever areas overlap Assume 9 case 1 hits	20 by 20 ft
(Deck span 18 ft Deck thickness 18 in. Safe cantilever 10.9 ft Pile cap span 8 ft 9 in.)			
Typical berth for comparison of repair methods	9 by 9 ft	13 by 9 ft	26 by 20 ft
(Deck span 20 ft Deck thickness 12 in. Safe cantilever 7 ft Pile cap span 10 ft)			
Special case considered in order to demonstrate flexibility of repair methods to adapt to other scenarios	N/A	N/A	40 by 16 ft

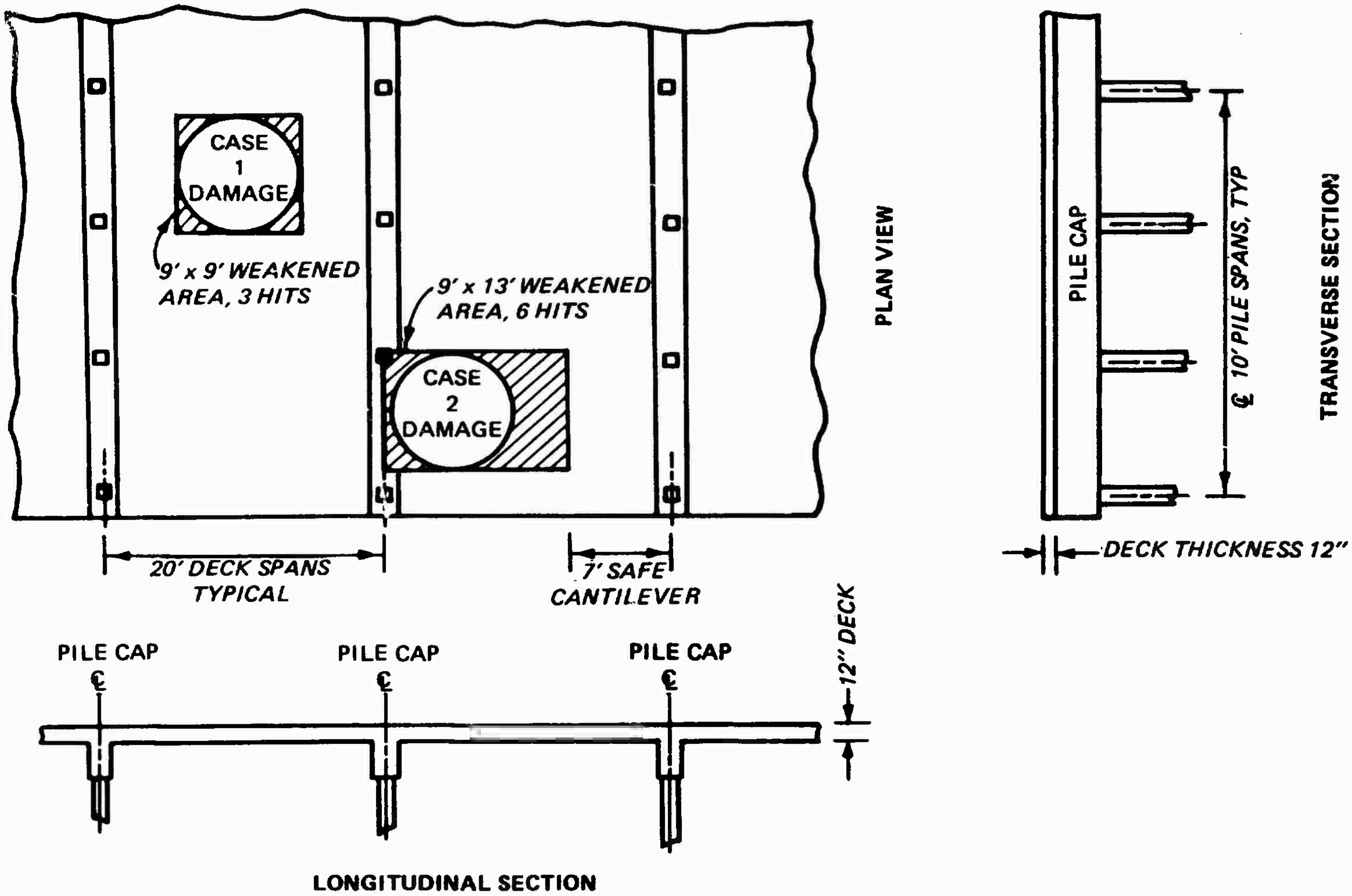


Figure 8.1. Typical damaged container berth

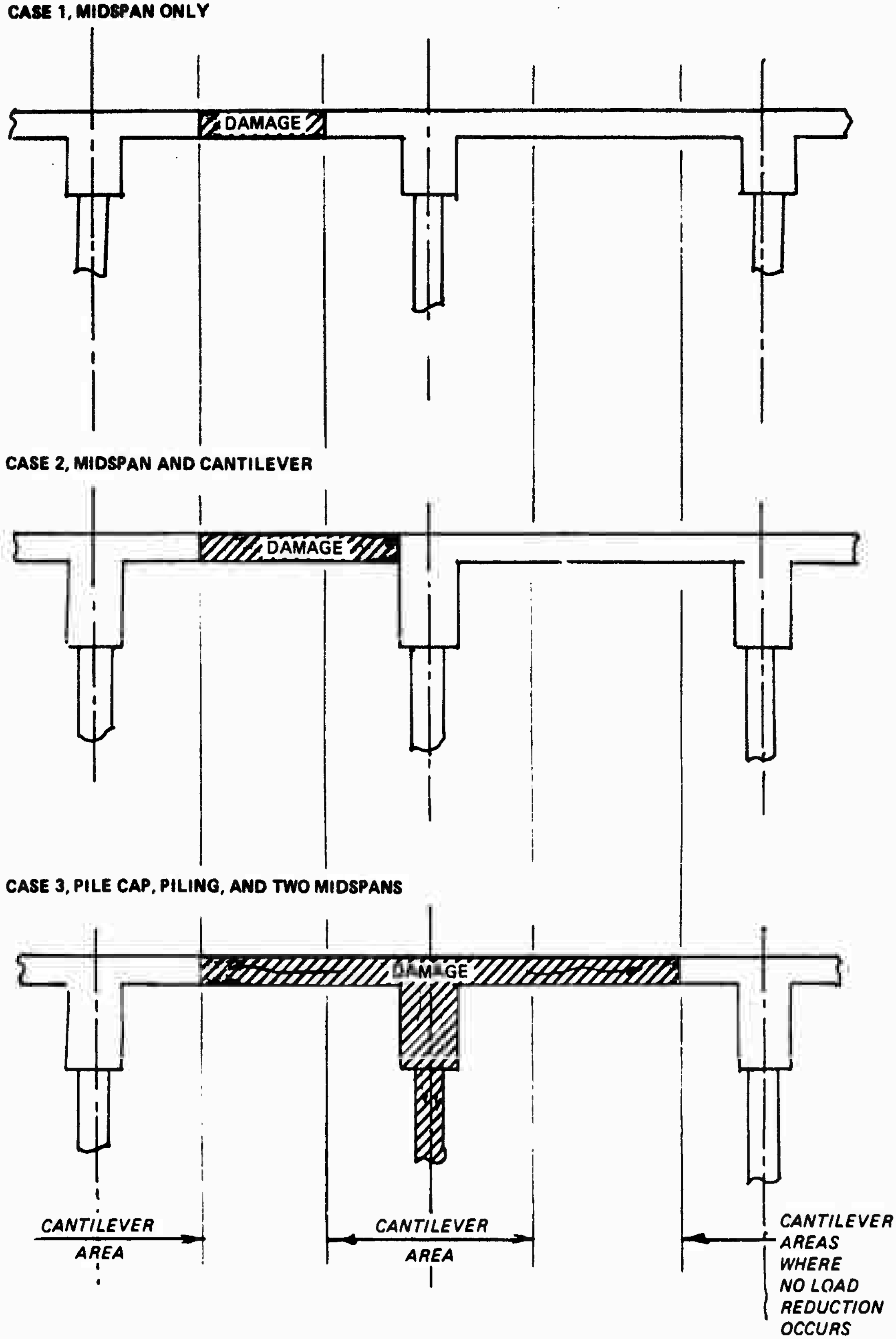
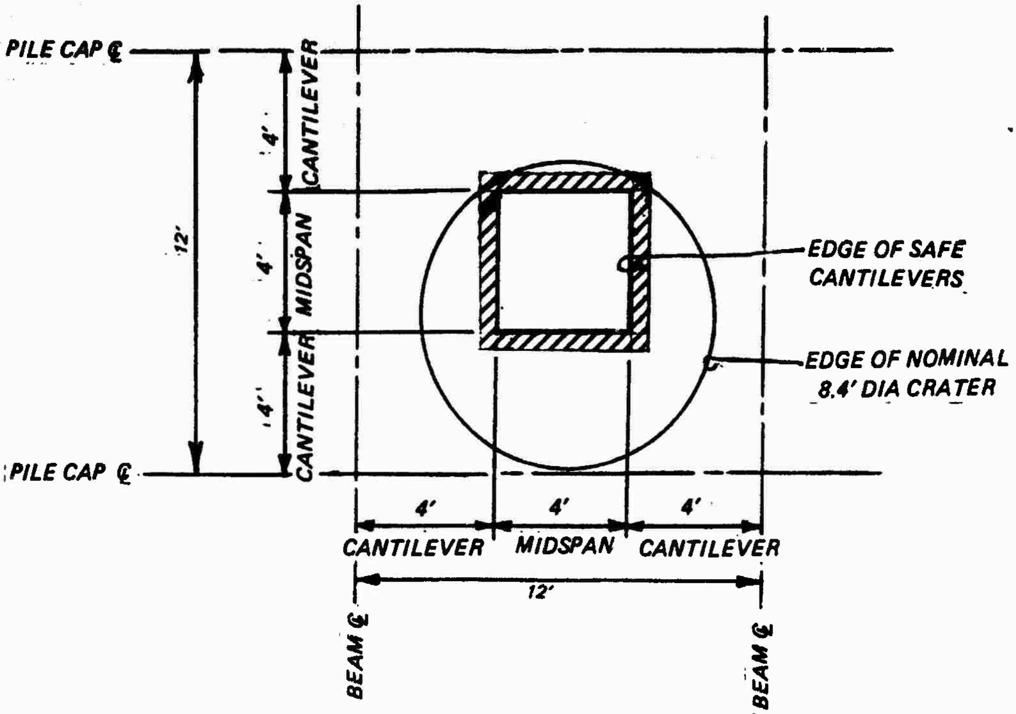
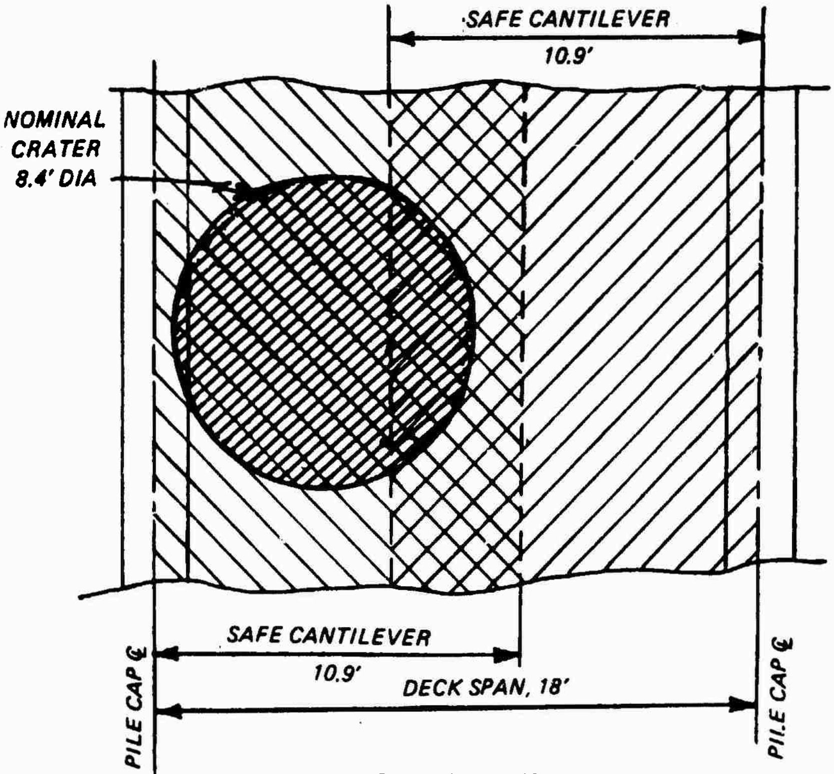


Figure 8.2. Three cases for damage repair



PIER 7, NAVSTA
PLAN VIEW



PIER 10, NAVSTA
PLAN VIEW

Figure 8.3. Impossibility of Case 2 damage, NAVSTA Piers 7 and 10

may be considered rectangular for the purpose of this design (see Section 6.1).

For the typical damaged container berth, 12 bomb hits were assumed. Three hits caused Case 1 damage, six hits caused Case 2 damage, and three hits caused one instance of Case 3 damage (Figures 8.4 and 8.5).

8.2 Steel Plate Concept (see Appendix D, for design and comparison calculations)

A damaged area of a pier may be covered quickly and easily with a steel plate. Investigation has shown that a 2-in. steel plate with a yield strength of 60 ksi can bridge a gap of 8 ft for a Cat 988 forklift with a fully loaded container. Deflection would be no more than 2 in. The moment is limited to the amount that causes yielding in the outer fibers of the plate. It is assumed that an 8-ft width of plate is effective in resisting the load and that no edge support is provided. This is the case in repairing a rectangular gap (see Figure 8.6). The foregoing assumptions are conservative if the crater is round and 8 ft in diameter. In this case, the plate would receive some side support and only one wheel could be in the center of the hole; the other would be on the undamaged surface of the pier. It might be possible to support one wheel of a fully loaded Cat 988 in the middle of an 8.4-ft crater with a 1-in., 60-ksi steel plate.

The assumption that an 8-ft width of plate resists the load of a CHV is not an exact assumption. It is contemplated that the plate will be supplied in 8-ft widths for container compatible transportation. At times the loads will be carried by two separate plates (see Figure 8.6) which will result in lower material stresses. Loads may also be carried by the edge of the plates which will result in higher material stresses. The 8-ft effective width is used for preliminary sizing during the conceptual design phase.

Plate repairs are attractive because of simplicity and ease of installation. Reference 8.1 states that 10,000 lb steel plates can be selected from a stack, loaded onto a truck, unloaded and placed in 1.5 hr. An 8- by 10-ft 2-in. steel plate which weighs 6,400 lb could be used to repair the 8.4-ft diam craters specified in the original scenario. At least six such repairs could be made in a 9-hr day. Cranes would not be required to move the plates

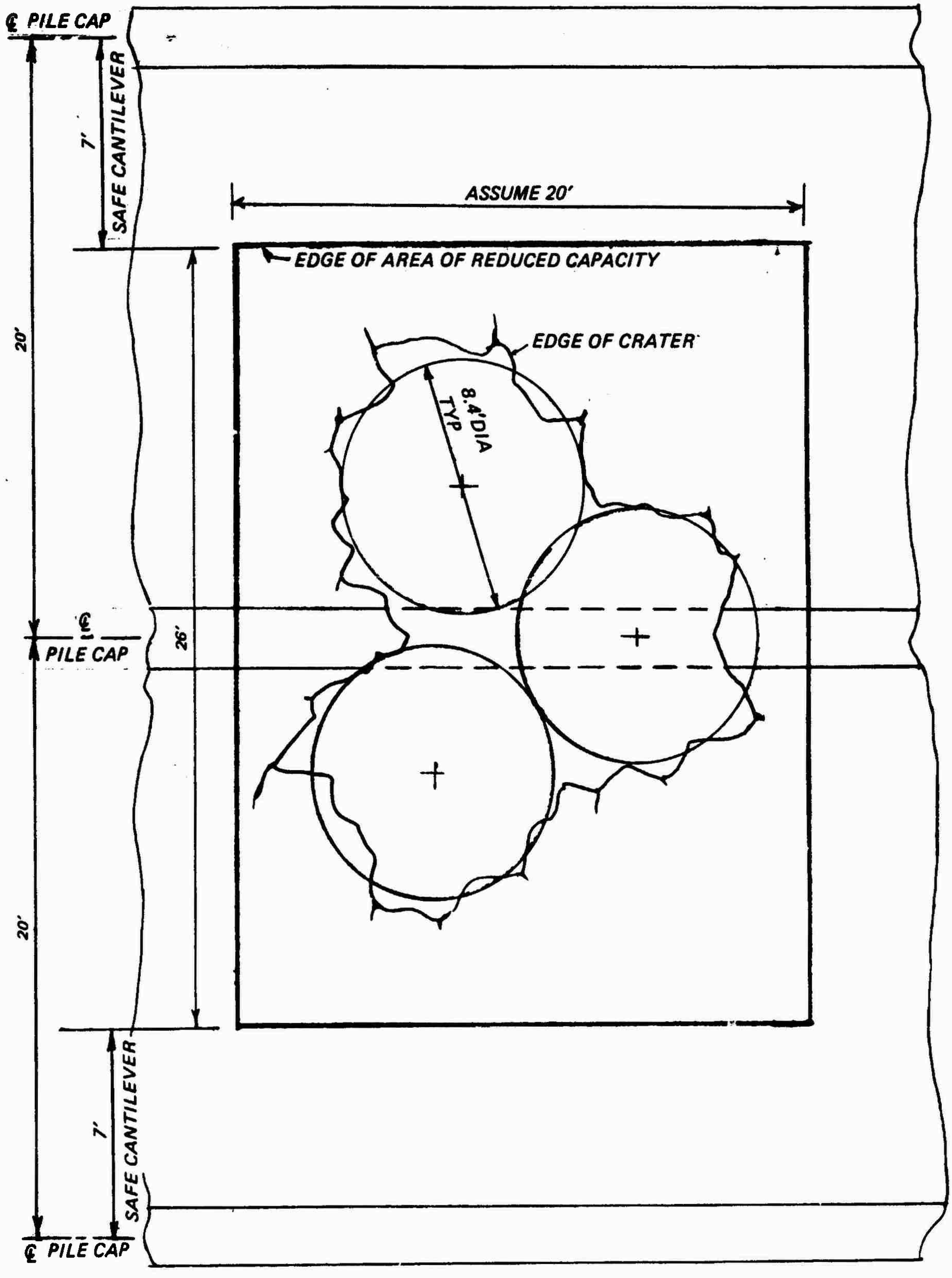


Figure 8.4. Configuration of Case 3 damage for the typical damaged berth

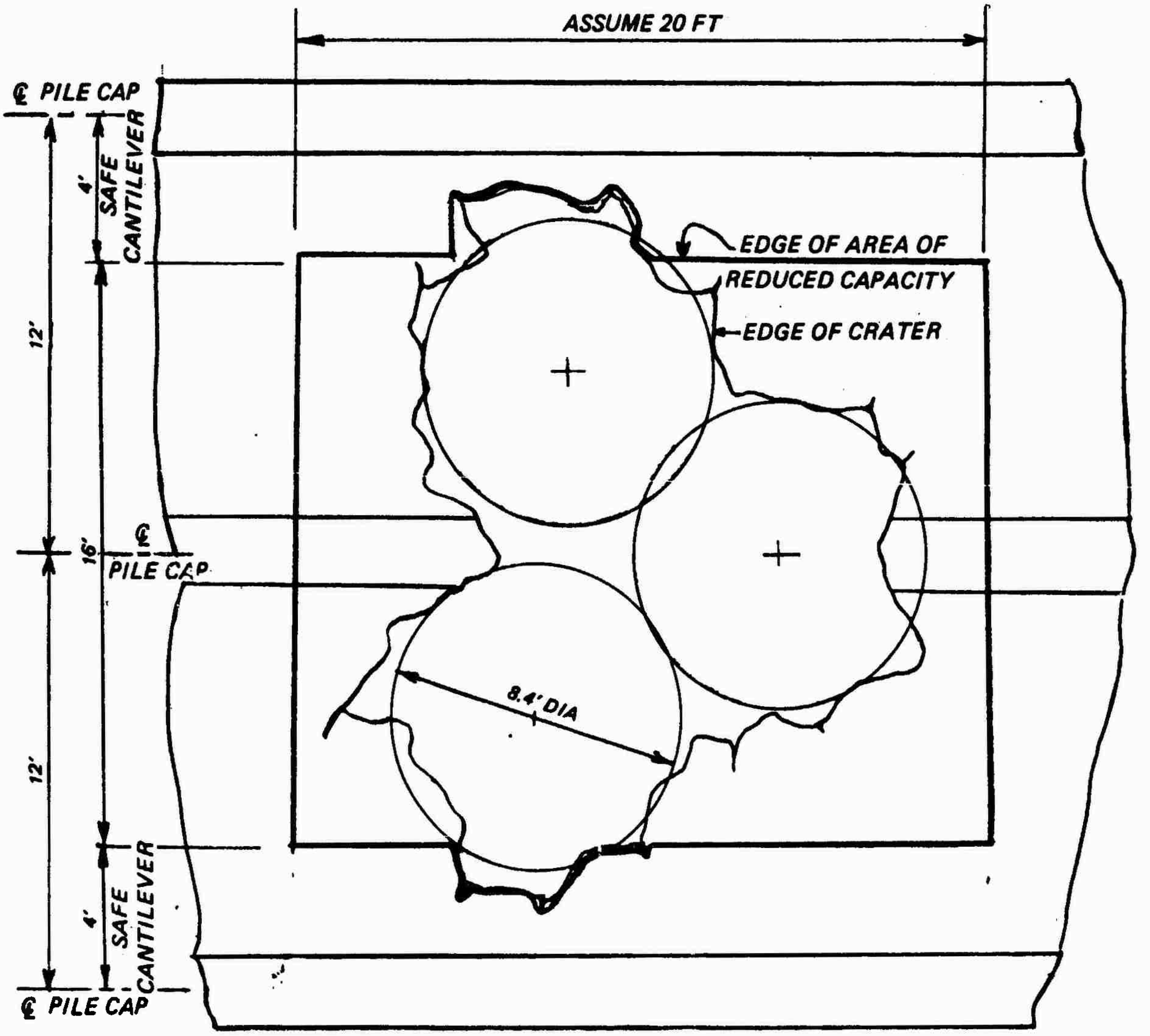
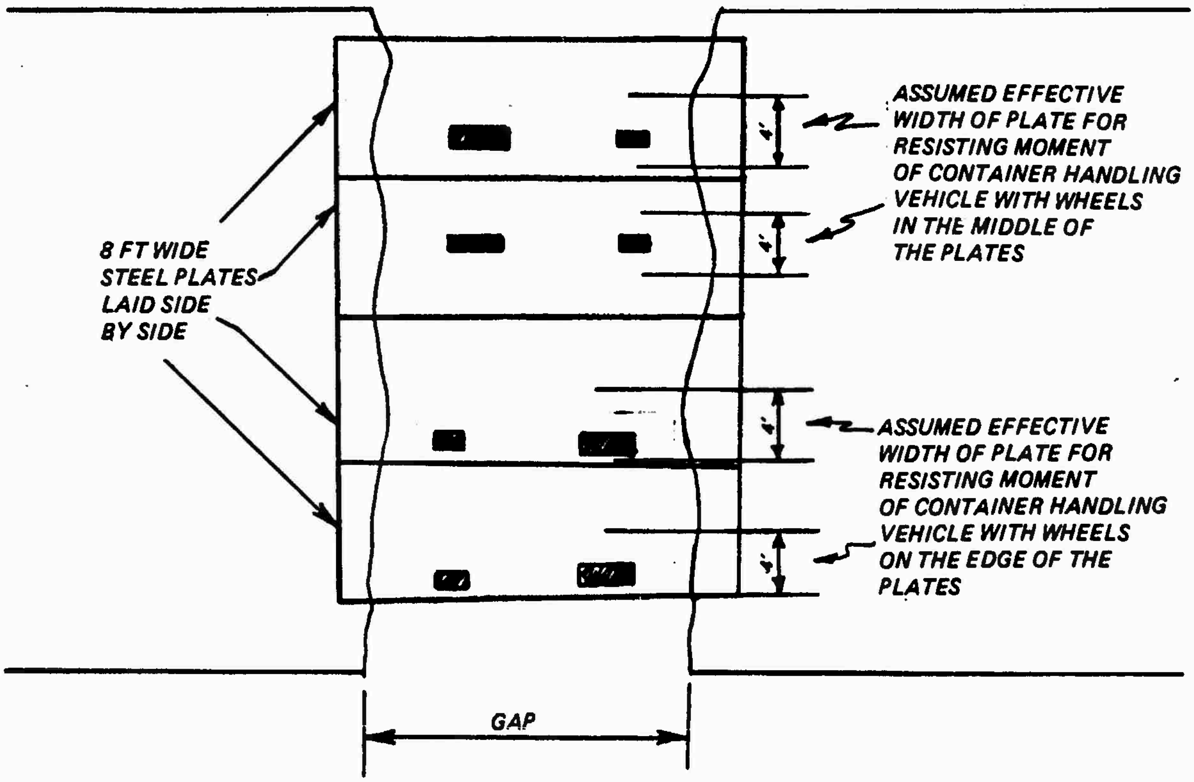


Figure 8.5. Case 3 damage to Pier 7, NAVSTA (Complete loss of two spans is assumed)



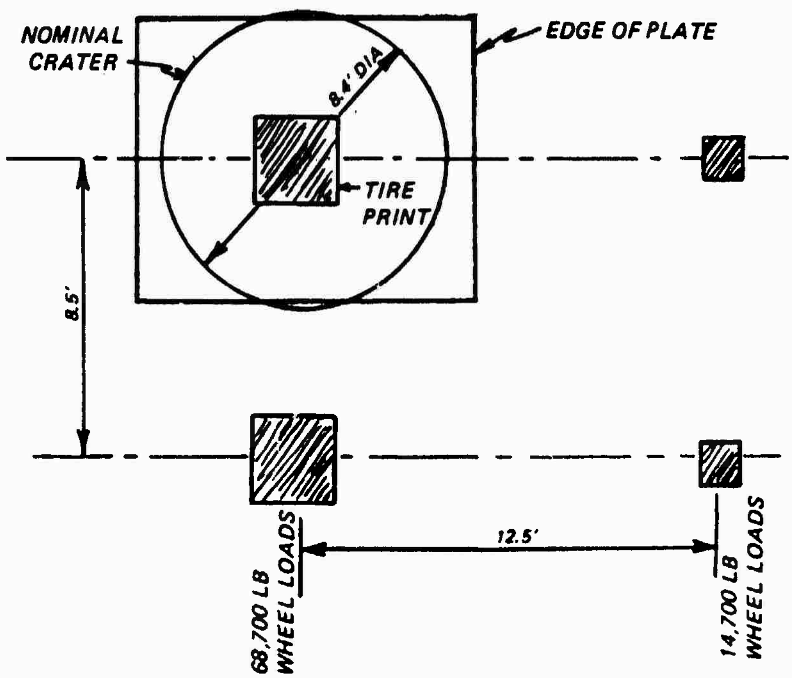


Figure 8.6. Assumptions for plate repair design

because the coefficient of friction between steel and concrete is low; a large vehicle could drag the plate to the installation site.

The plate may be secured against sliding at the repair site by anchoring it to the undamaged deck with anchor bolts or by attaching rods to the plate which will protrude down through the open area in the deck and bear against the edges of the crater in case of slippage. Holes in the plates should be provided on 12-in. centers for bolts, attachments, and handling aids.

The raised edge of the plate will not cause operational problems for CHV's.

Steel plates will exhibit noticeable deflection before ultimate failure. Personnel may easily observe the deflection so they are warned of impending overload. When a plate resists a moment, the stresses are greatest in the outer fibers of the plate. When the outer fibers yield, the inner fibers are still in the elastic region of their stress-strain curve. This gives the plate reserve capacity from complete failure. After outer portions of the plate have reached the yield limit, the plate still has reserve capacity. Small overloads will cause permanent distortion of the plate, but not complete collapse. If the plate is bent by handling or overload, it may be placed so that it arches up. It may fail in fatigue, however, after being bent several times.

The moment resistance of the plate increases geometrically with its thickness (see Figure 8.7). A 2-in.-thick, 60-ksi plate offers sufficient moment resistance to be useful for a variety of applications. The amount of field modification required for plate installation is minimal, and the increased difficulty of fabricating high-strength plate is not a critical problem. For these reasons, it is suggested that a 2-in.-thick, 60-ksi steel plate be used to span gaps up to 8 ft for heavy container handling equipment, up to 18 ft for the 1,000 lb/sq ft loading, and up to 23 ft for the HS 20-44 loading. Maximum deflections will be approximately 2, 10, and 13 in., respectively.

The 60-ksi, 2-in. steel plates are not available as a standard product specified in Reference 8.4; however, high-carbon proprietary steels are available in the 50- to 80-ksi range (Ref 8.5). ASTM A514 Quenched and Tempered 100-ksi steel is available as a standard product. ASTM A514 can be welded with some difficulty and has reasonable toughness and ductility. An 8-ft effective width of plate which is 2-in.-thick, 100-ksi steel plate will span a

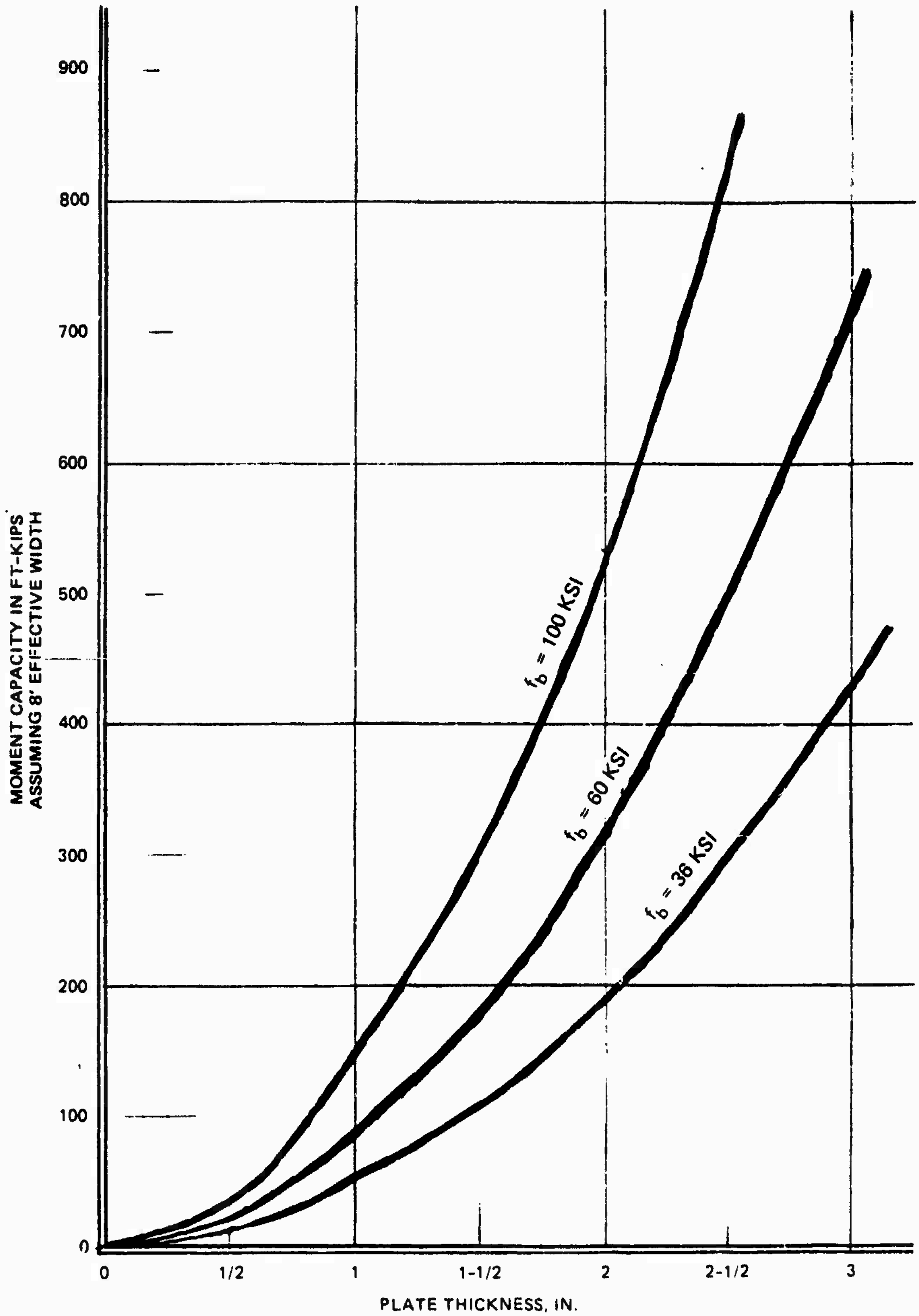


Figure 8.7. Moment capacity of steel plates of various strengths (Effective width equals 8 ft)

gap of 13 ft with a Cat 988 or 250-ton truck crane, 23 ft for a 1,000 lb/sq ft load and in excess of 30 ft for the HS 20-44 load. Maximum deflections are 10, 27, and more than 30 in., respectively. The length of a gap spanned by 100-ksi, 2-in. steel plate will probably be limited by deflection criteria rather than bending failure.

If one steel plate does not offer sufficient resistance, another one may be stacked on top, and the resistance will be doubled.

8.3 Erector Set Concept (see Appendix D for detailed design and comparison calculations)

A larger moment carrying capacity may be created by separating the tension and compression areas of a flexural member. Repair modules could be made with wide flange steel beams which are sandwiched by 1-in. steel plates (Figures 8.8 and 8.9). The assembly could be bolted together to develop the composite strength of the whole module (Figure 8.10). The following parts would be required:

- a. Top and bottom plates 8 by 40 ft, 1 in. thick with holes drilled on 4-in. centers for 1-in. bolts over the entire area (Figure 8.11). These will act as tension and compression flanges.
- b. Wide flanged rolled sections with corresponding holes in the flanges. These will provide shear resistance between the tension and compression flanges.
- c. Some type of transverse stiffening member to ensure that the entire width of the section acts in composite action (Figure 8.12).
- d. Approximately 1-in. diam bolts.
- e. Special clips or cages which will hold the nuts in place while the bolts are being turned. The nuts may be inaccessible during certain stages of construction.
- f. The 24-in.-wide by 1/2-in.-thick plates with bolt hole patterns to match other components. These will be used to splice the 1-in. plates as necessary.
- g. End ramps for nonflush repairs. These could be made from materials salvaged in the TO.
- h. Angle iron with matching hole patterns for the creation of boxes (see Figure 8.13).
- i. A shim package for matching the repair components to existing structures. All these components would be packed into containers or assembled into racks which are compatible with containers (Figures 8.14 and 8.15).

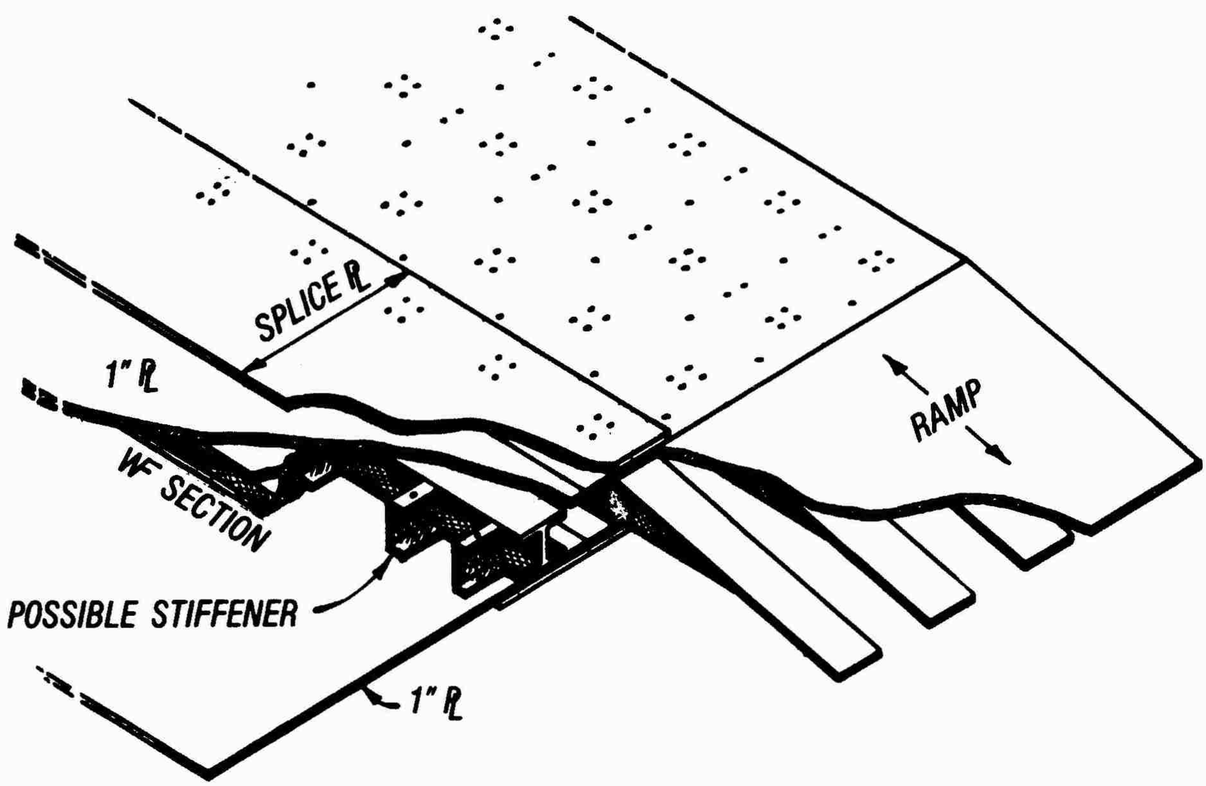


Figure 8.8. Isometric view of Type A module

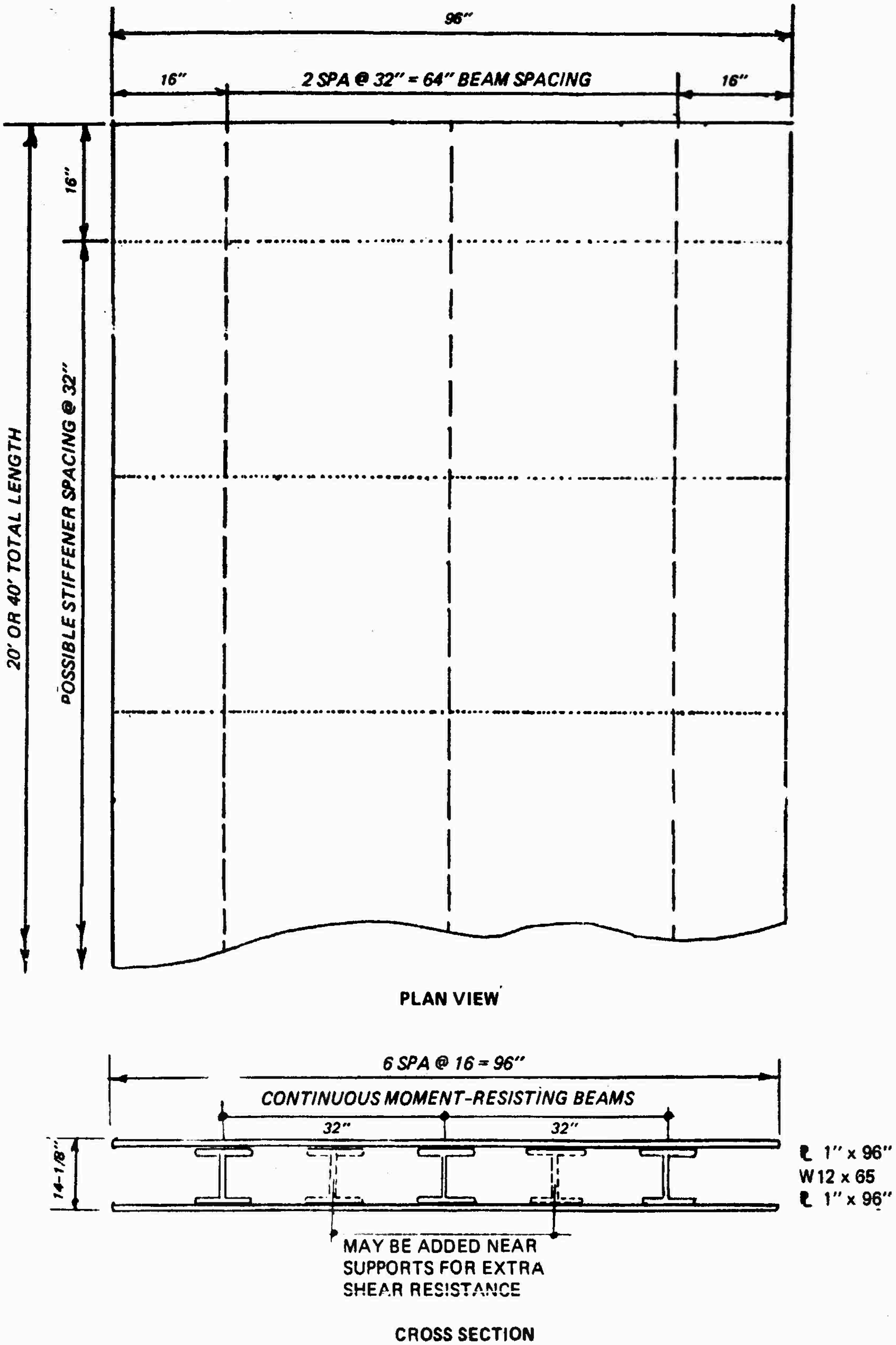


Figure 8.9. Plan and cross section, Type A repair module

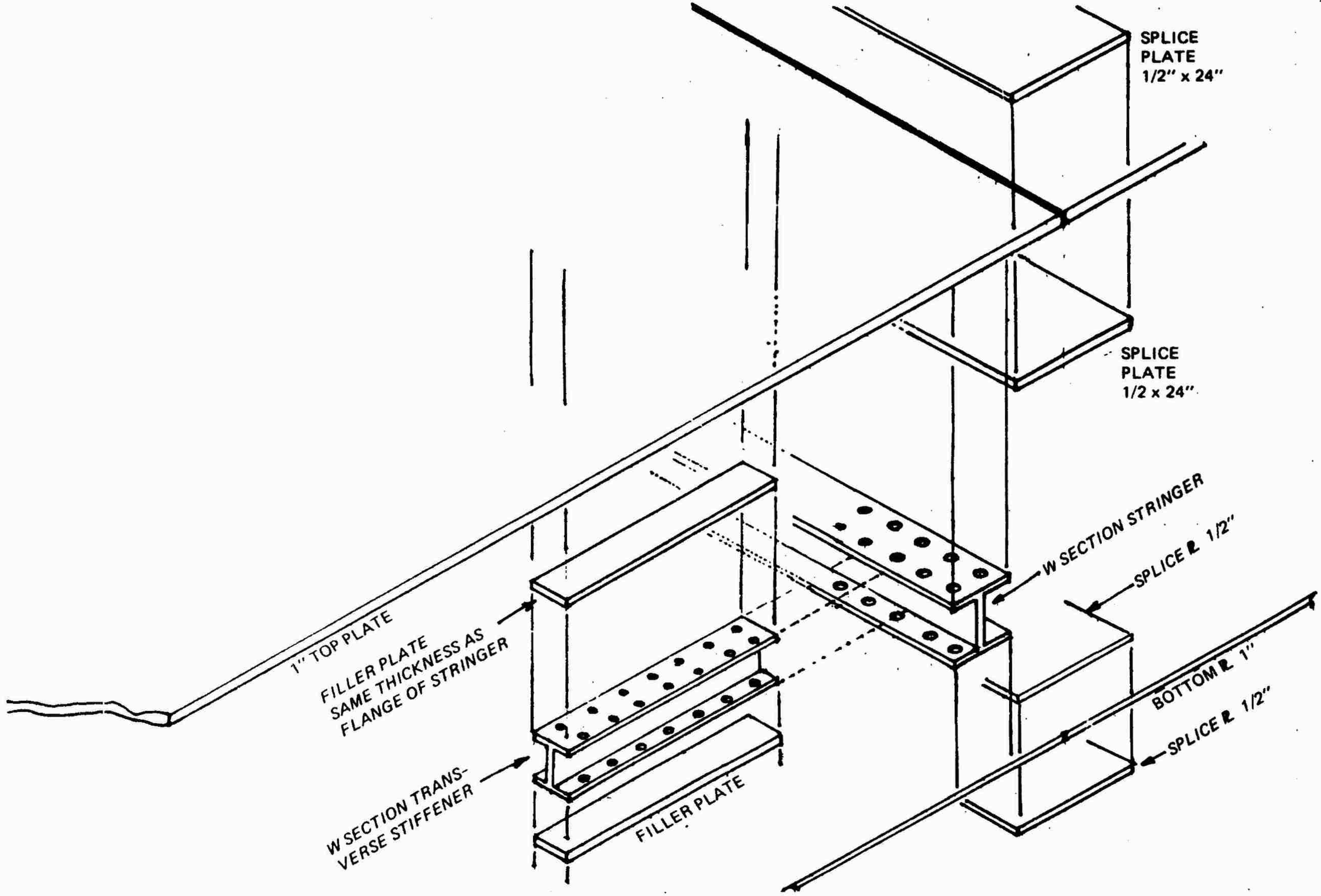


Figure 8.10. Exploded isometric view, Type A repair module

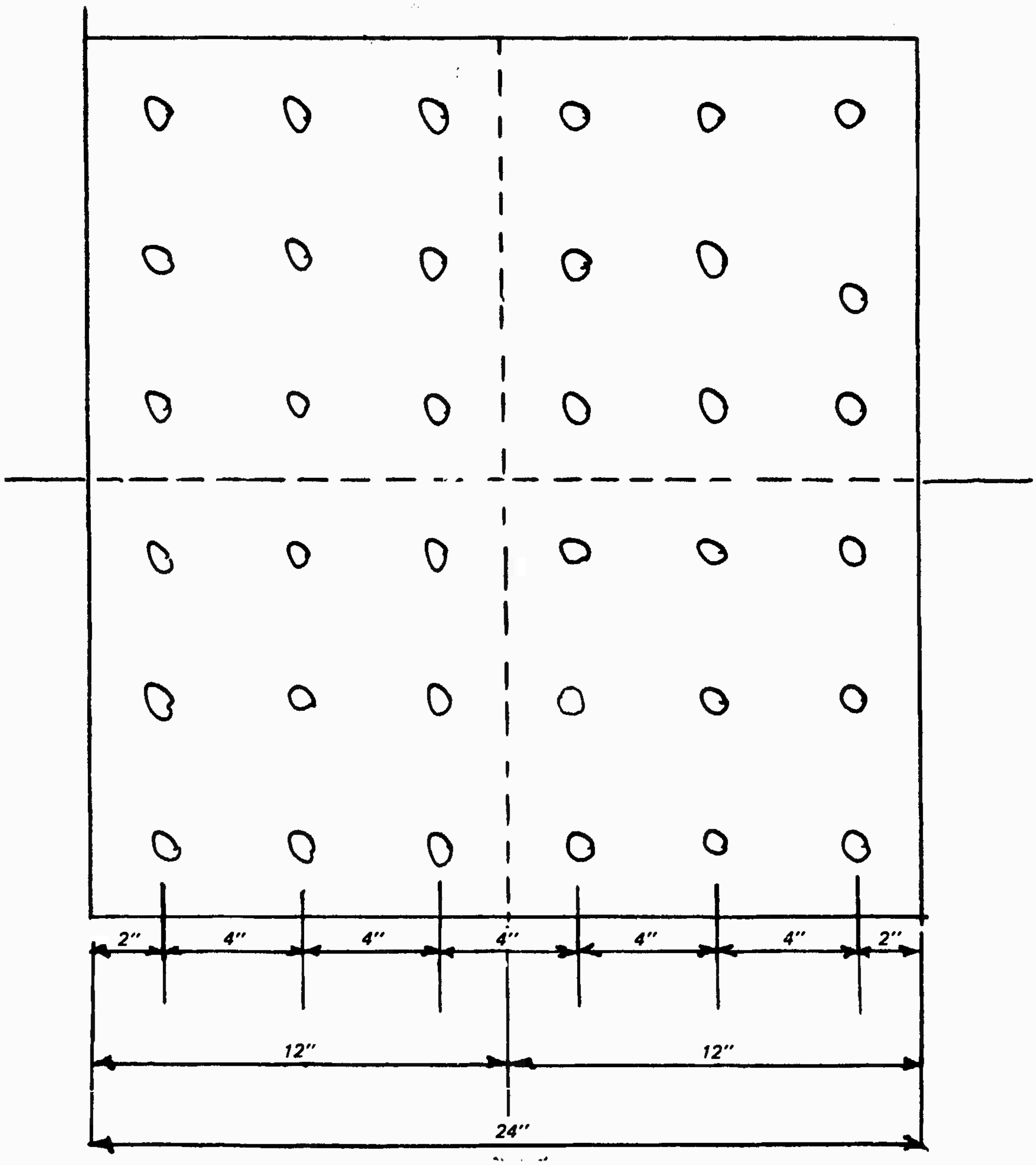


Figure 8.11. A 24-by 24-in. plate which illustrates placement of boltholes on 4-in. centers

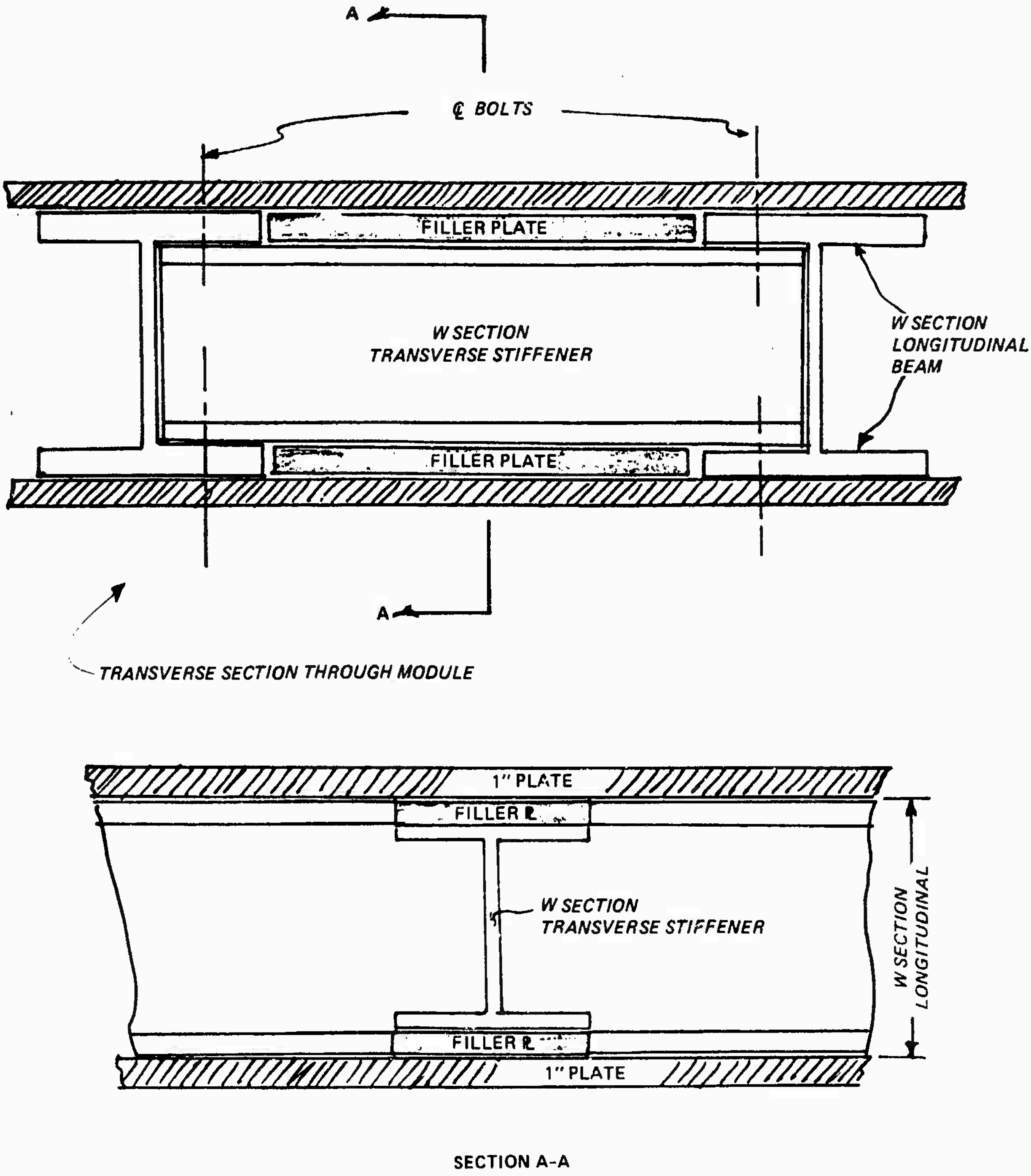


Figure 8.12. Possible transverse stiffener detail

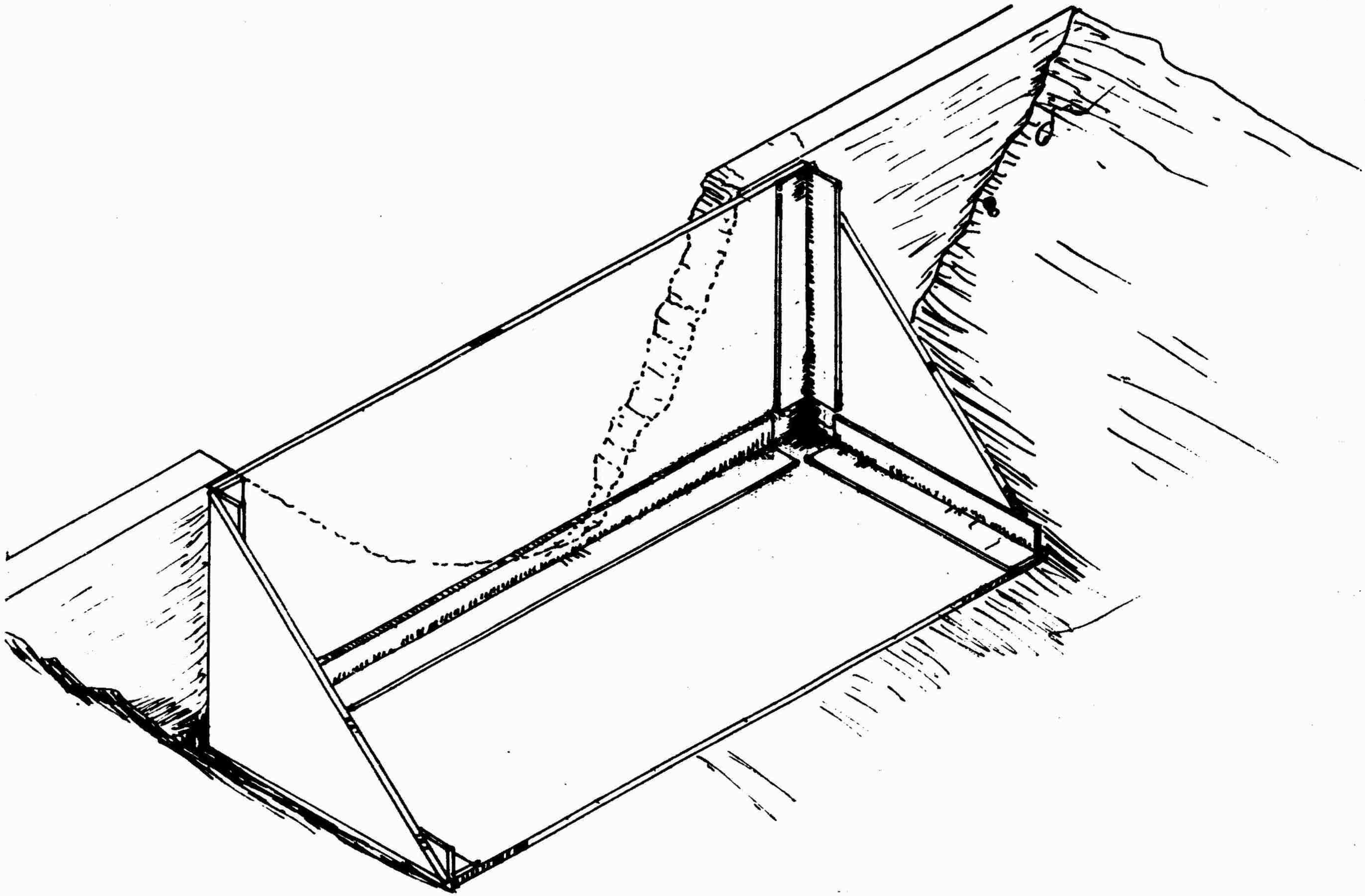


Figure 8.13. Expedient quay wall

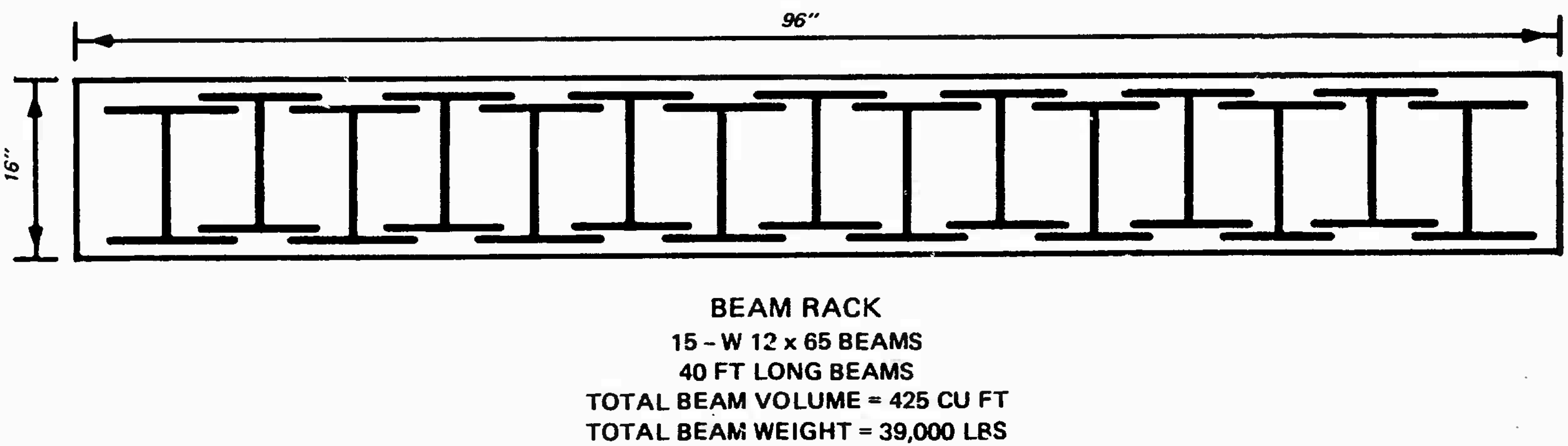


Figure 8.14. Typical container compatible beam rack

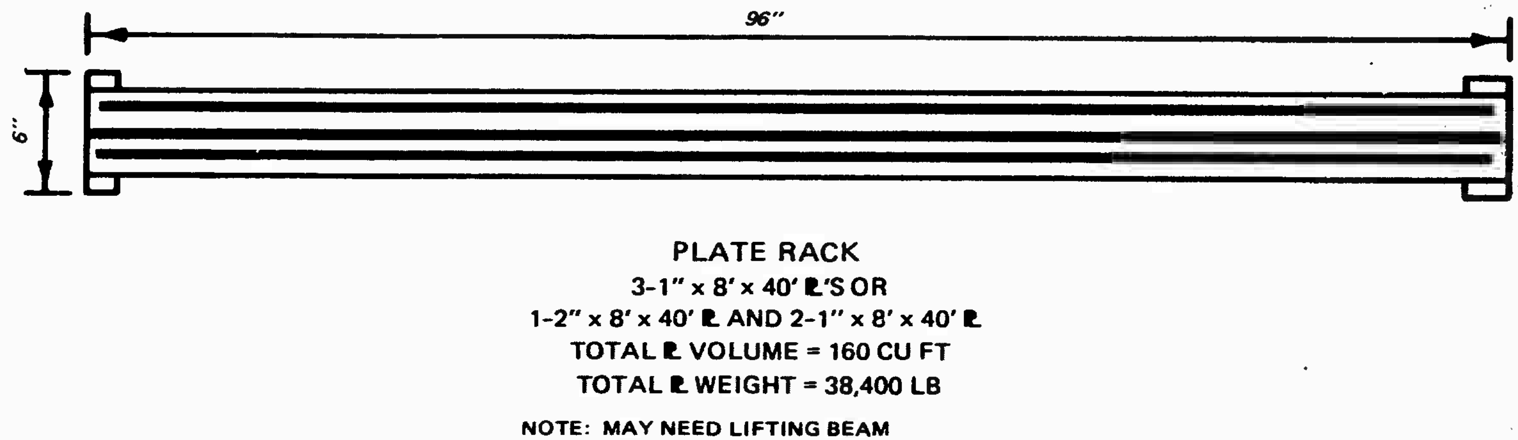


Figure 8.15. Typical container compatible plate rack

The repair components can be configured in several different ways:

a. The modules may be laid on top of the deck over the damaged area and ramps provided to accommodate vehicles (Figure 8.16a).

b. The deck may be sawcut to accept the modules so their tops will be flush with the deck. The modules will be supported by bearings which are attached to the bottom of the deck or to the pier caps (Figure 8.16b).

c. Steel beams could be attached to the plate so they protrude down through the damaged area only. The repair would be supported by the areas where the plate overlaps the undamaged portion of the deck (Figures 8.17 and 8.18).

d. A combination of steel beams and plates could be assembled to create an expedient pile cap. A steel beam would be clamped on either side of the undamaged portion of the pier cap. If extra strength is needed, the plate would be bolted on the top and bottom of the two beams. The use of a shim package would be necessary to provide proper spacing so that the holes in the plates and the beams line up (Figures 8.19 and 8.20).

e. Any of the previously mentioned repairs could be supported by piling. An appropriate attachment could be made to the bottom of the module to distribute the load. This is similar to the umbrella concept (Figure 6.6).

f. Placement of beam and plate elements could be optimized so the repair provides the correct amount of moment and shear resistance and transverse stiffness in the areas where they are most needed (Figure 8.21).

g. The steel beams could be used as piling, if necessary.

h. Using heavy angle, plates could be assembled to form rubble boxes for gravity retaining walls for expedient quay wall repair (Figure 8.13).

The repair components may be configured in ways that will make them useful for other military engineering projects:

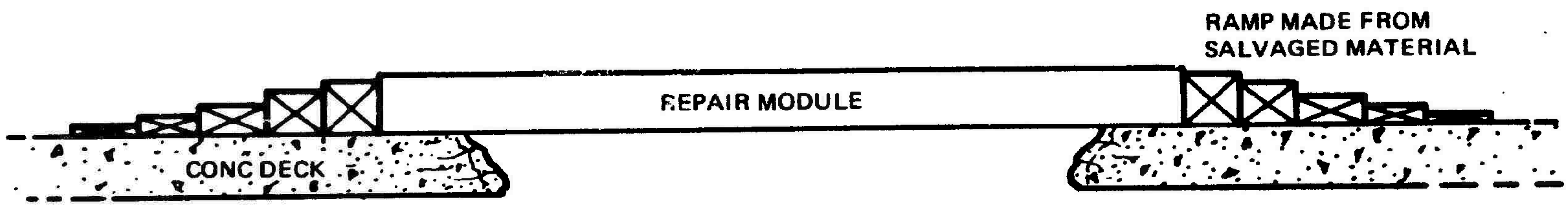
a. Bridge repair.

b. Gravity retaining walls.

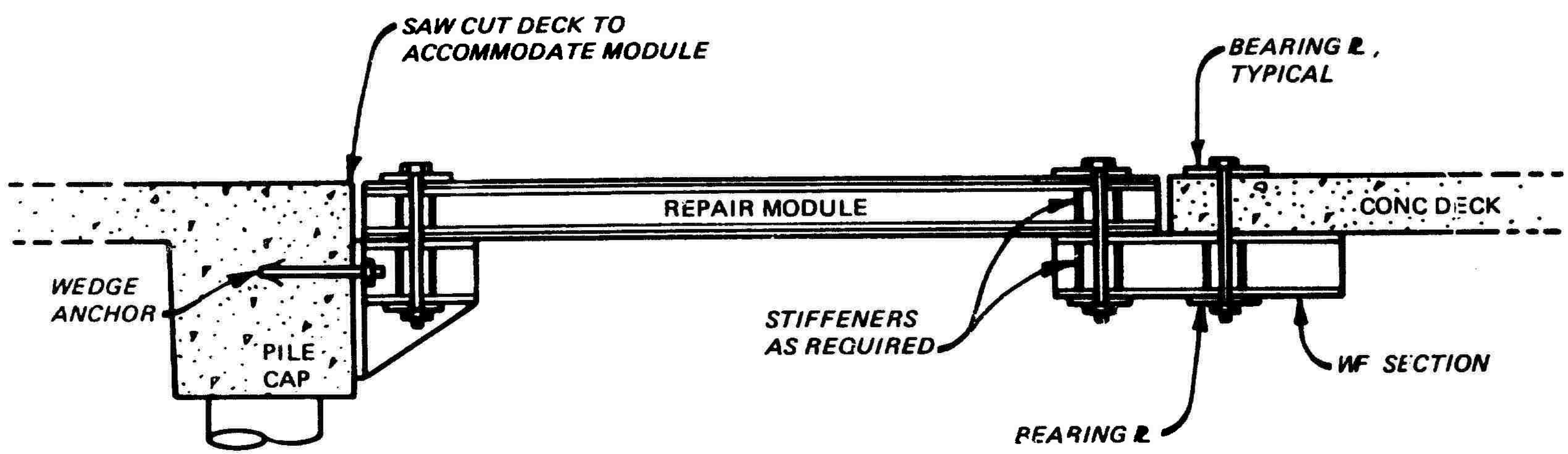
c. Fortifications, blast shelters.

The plates may also be useful for highway and airfield repair. The greater strength of the steel may eliminate the need for careful backfill and compaction, but the slippery surface and the bumps at the edge of the repairs may limit their usefulness.

In Appendix D, designs are developed for two types of repair modules. Type A modules are similar to the cross section in Figure 8.9. Type B modules are Type A modules without the bottom plate. Type A or Type B modules are emplaced as shown in Figure 8.16.



a. Repair module laid on top of deck to cover damage



b. Flush repair using repair module

Figure 8.16. Alternate installation methods for repair modules (Type A or Type B)

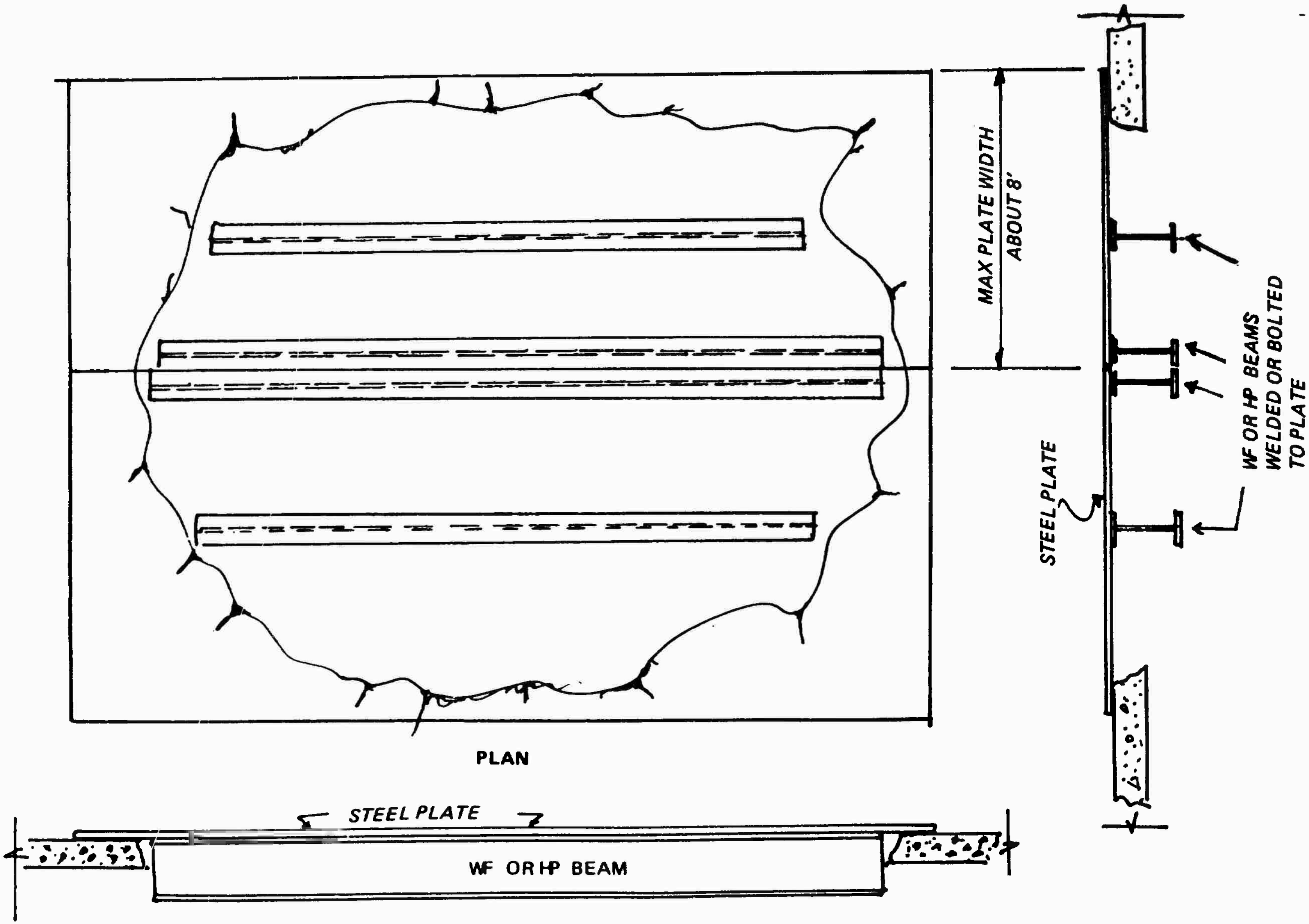


Figure 8.17. Repair using steel plate reinforced by steel beams (Reinforced plate subconcept)

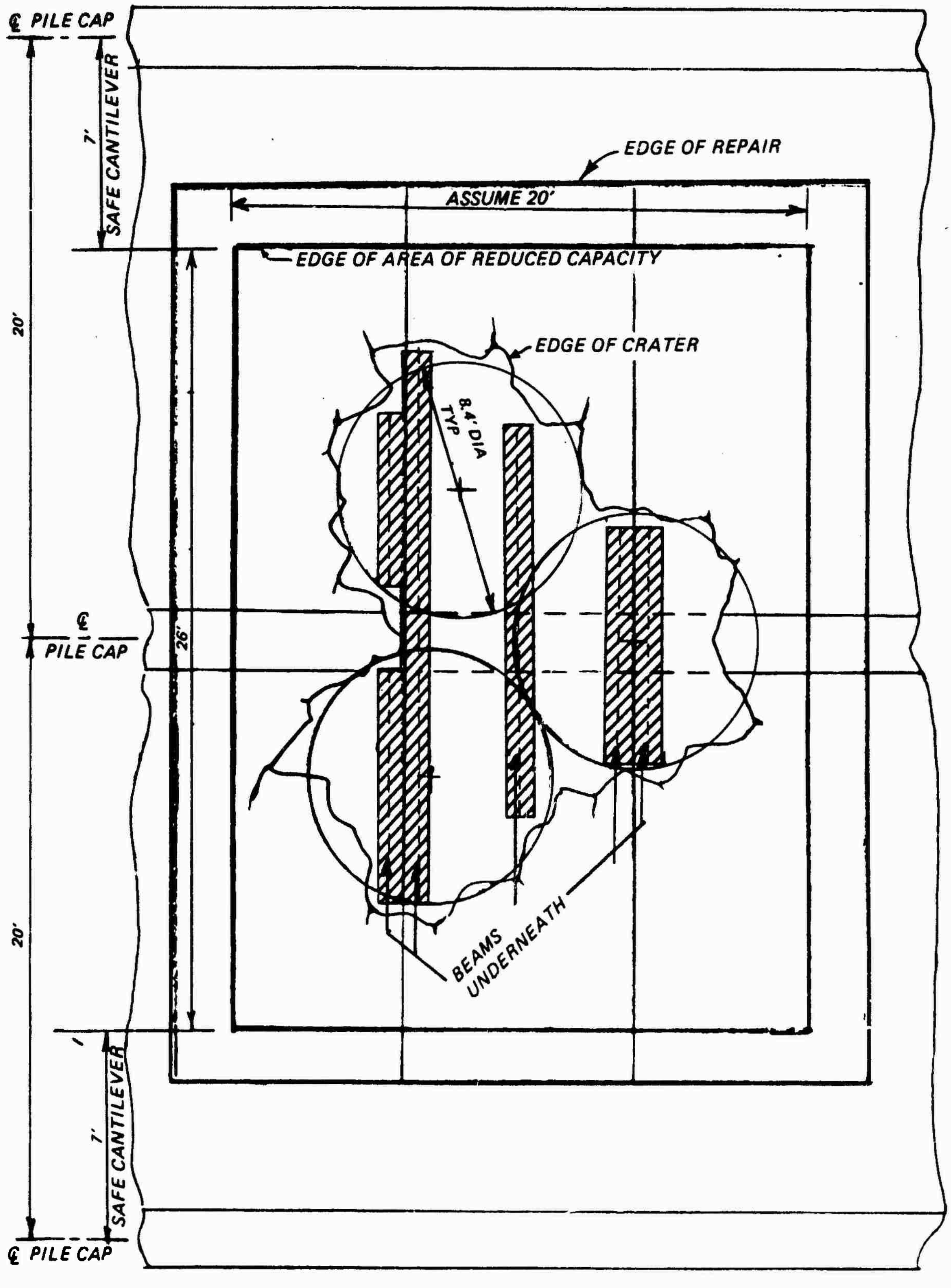
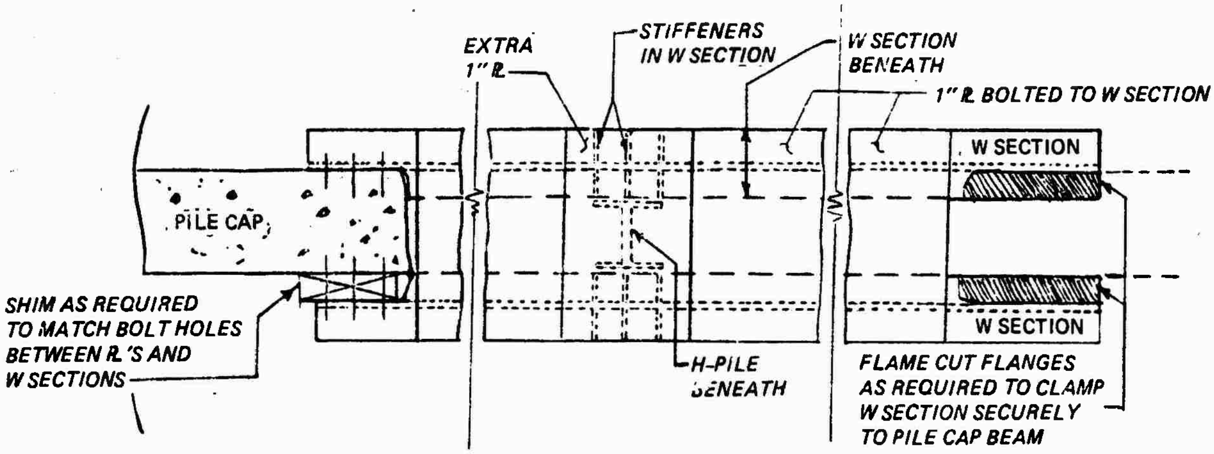
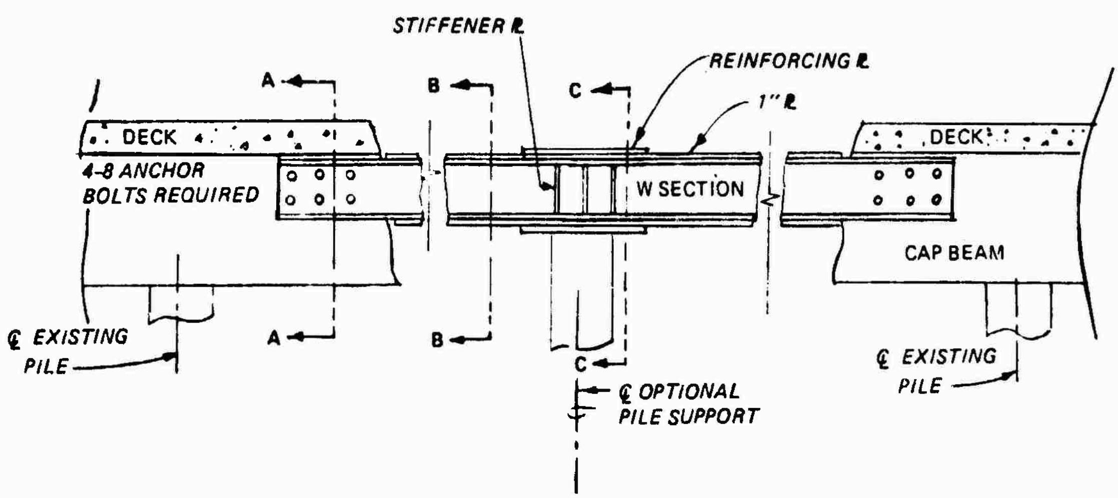


Figure 8.18. Steel plate reinforced with steel beams (Repair for Case 3 damage, 60 ft of steel beam required, 3 plates, 8- by 30-ft, 1 in. thick required (Reinforced plate subconcept)



PLAN VIEW



ELEVATION VIEW

Figure 8.19. Expedient pile cap, plan and elevation views

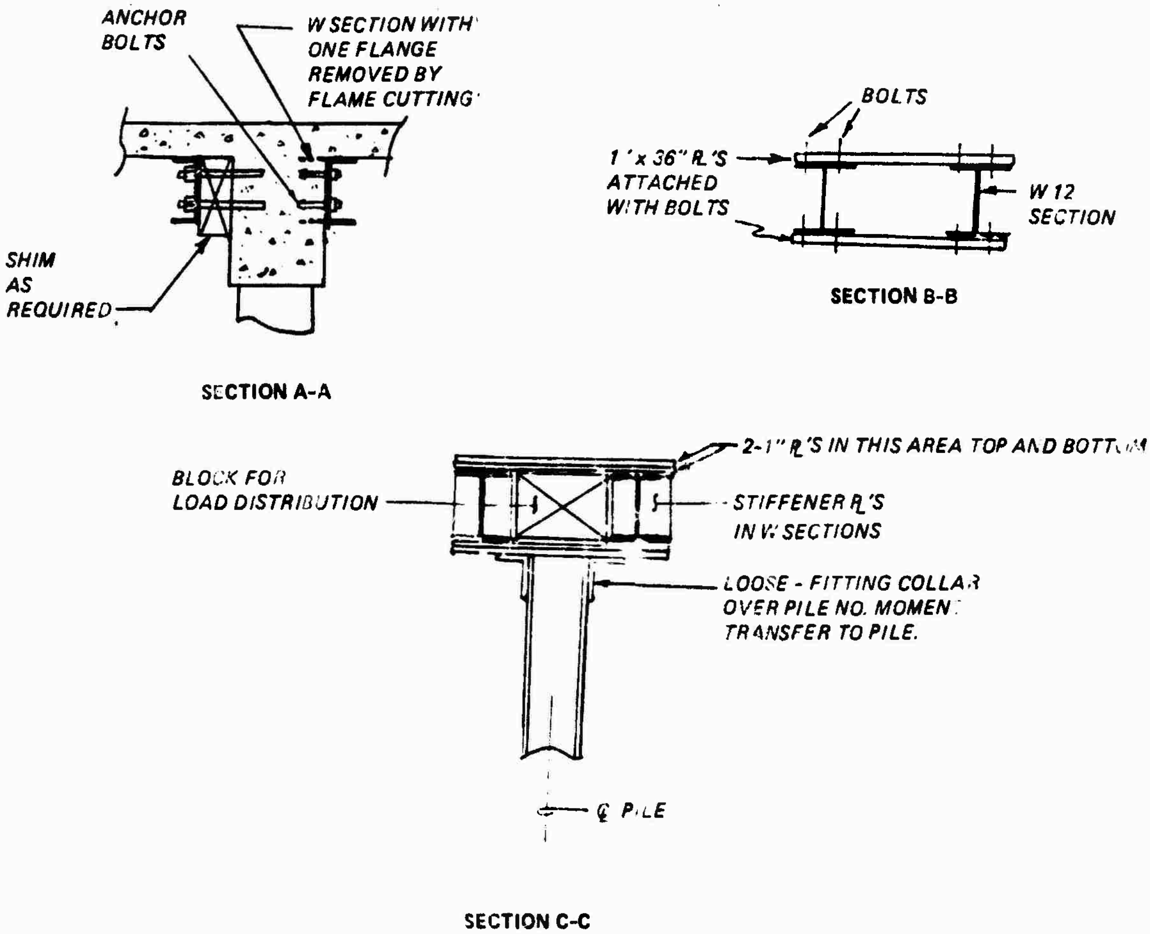


Figure 8.20. Expedient pile cap, cross sections

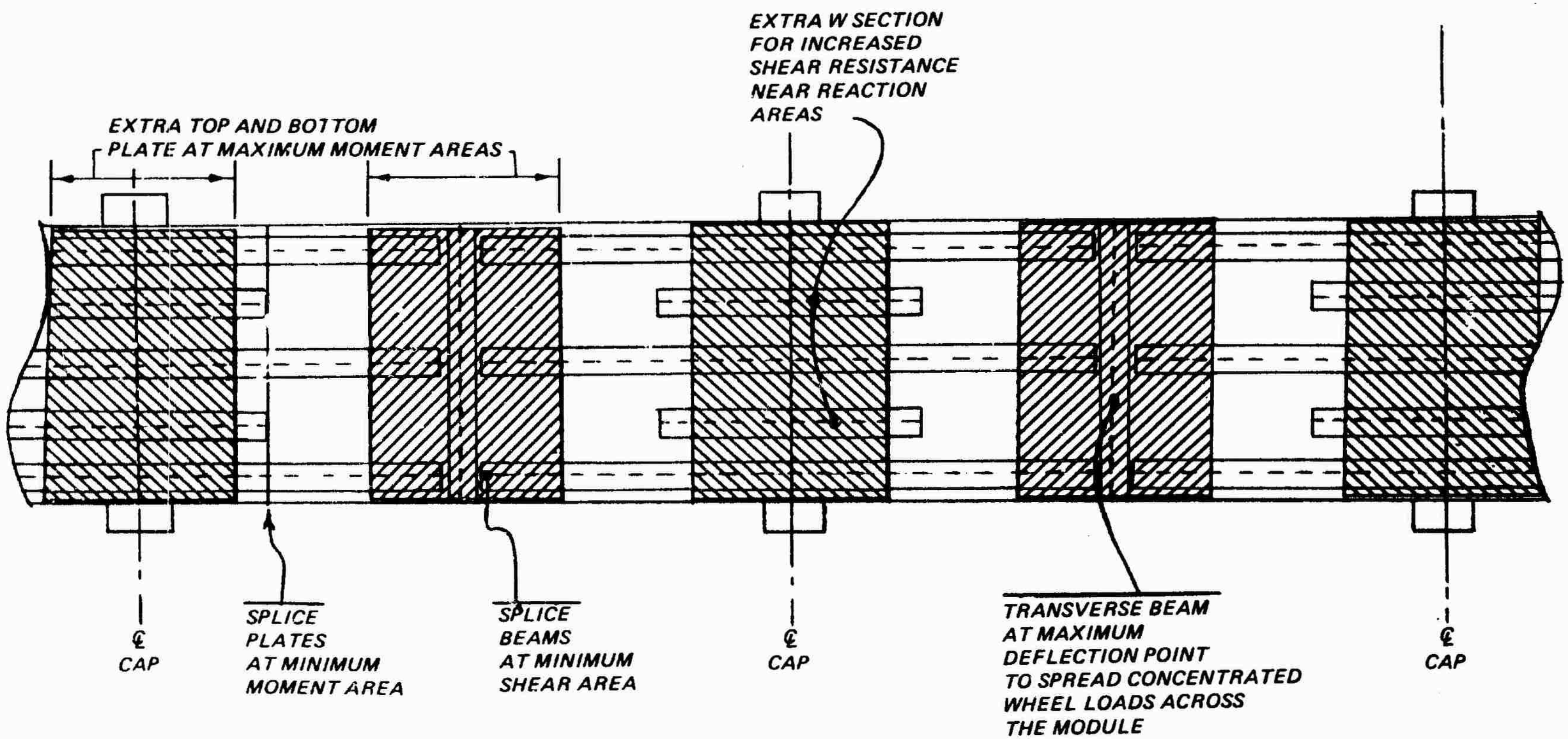


Figure 8.21. Optimized component placement for repair modules

A Type A module might consist of two plates 8 ft wide and 1 in. thick separated by W12X65 beams on 32-in. centers. Two modules would have to be spliced together to provide sufficient width for container handling equipment. A325, 1-in.-diam bolts are used with bearing connections assumed. The 44 bolts acting in single shear are required to secure the plate to each end of each beam. Nine bolts acting in double shear are required for each foot of splice for the 1-in. plate. About 2,500 bolts will be required to build a 40- by 16-ft bridge unit.

Each module will weigh 44,200 lb after transverse stiffeners and other components are added. This is less than the maximum weight of a military container. An entire 40- by 16-ft bridge will weigh 88,400 lb after splice plates are added. An 8-ft width of the repair module will have a moment resistance of 6,450 ft-kips which is sufficient to carry a P&H 6250-TC over a 40-ft span. Maximum deflection will be less than 3 in.

The 1-in. bolts were chosen because they are strong enough for each connection, yet small enough to accommodate bolt hole patterns on beam flanges and splice plates. Hand assembly is also possible if personnel are supplied with proper equipment.

Figure 8-22 shows a feasible assembly method for Type A modules. Assembly could be simplified by building the bridges on racks which allow access to both sides of the structure. If a crane were available which could lift both modules after they have been spliced together, assembly would be expedited.

Critical items to determine assembly time include obtaining material from stockpile and initial alignment, bolting time, and handling time for tilting and aligning the modules during assembly. It is assumed that a team of 10 does the bolting and that a crane and truck are available for handling and transportation. Two Cat 988 forklifts could be used instead of the crane. Reference 8.1 indicates that 10,000-lb steel plates may be moved in 1.5 hr each. This includes time to select the plate from a stockpile, position the crane and truck, and load and unload. The four plates could be obtained in 6 hr by this standard. Time could be saved because the plates might be obtained from the same stockpile and they would be going to the same place. For estimation purposes, it is assumed that all steel components could be laid out and aligned in one work shift of 10 hr. According to Reference 8.2, each man should be able to install 100 bolts in a day. A 10 man bolting crew should be able to install the required bolts in two workshifts. One more

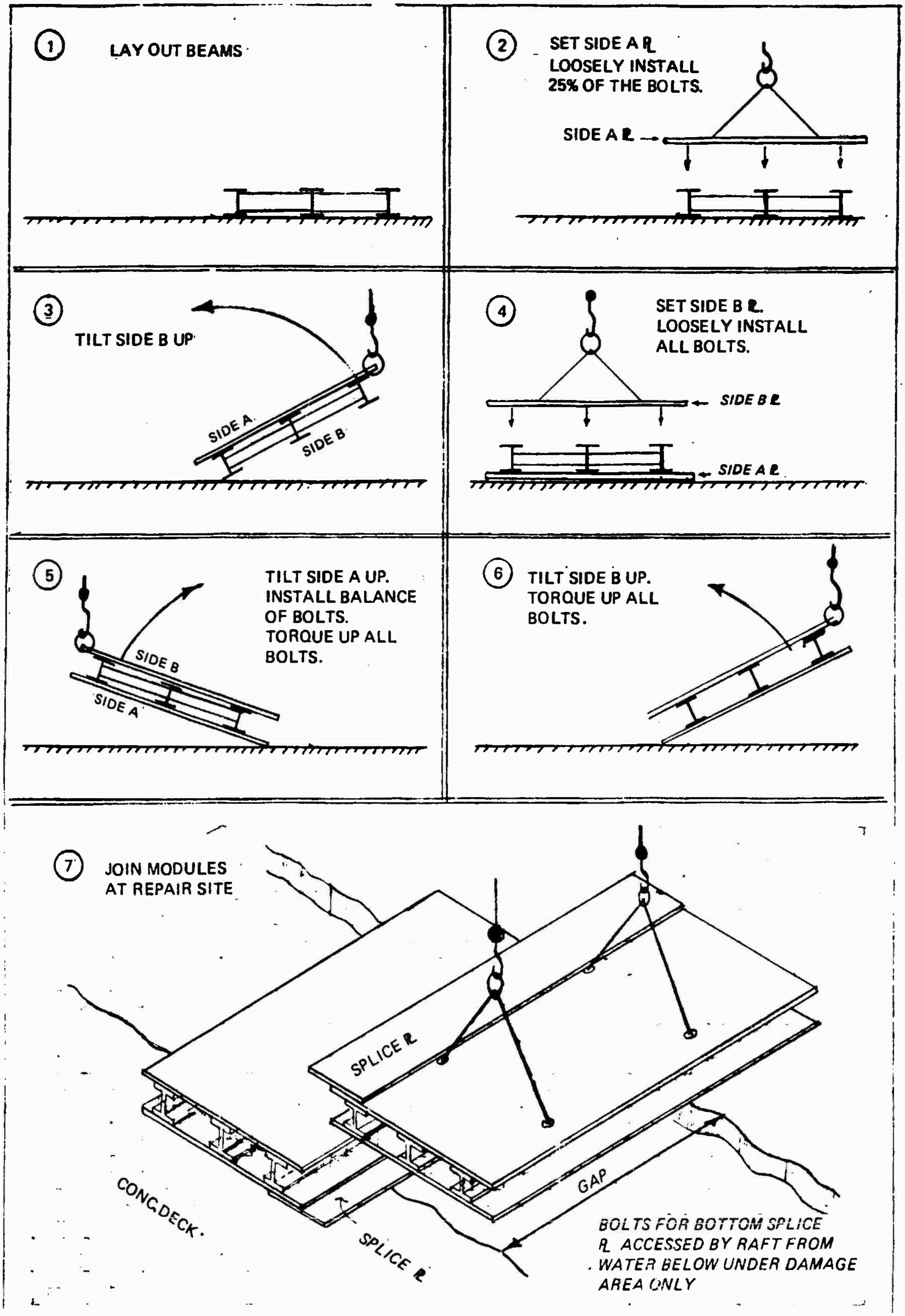


Figure 8.22. Assembly of Type A repair module

workshift would be required for tilting and final positioning. This bridge unit could be assembled from materials in a stockpile in four 10-hr workshifts, two calendar days if the crews were double shifted.

Assembly and prepositioning of the components could be managed in several different ways. The units could be bolted or welded together. Most of the effort was used to investigate the bolting option because it is a lower technology approach and because it could be accomplished with hand tools, if necessary. Assembly could take place at any time between the fabrication shop and the final place of use. Preassembly shortens installation time but decreases the flexibility because the planner is committed to the assembled configuration. Preassembly also increases the shipping cubage required. If all the components are not needed immediately when they arrive at the TO, it might be wise to preassemble some of the modules and, when the need arises, ship them to the proper location by truck or barge.

Three subconcepts of the erector set concept were considered for comparison with other repair systems. They were as follows:

a. Preassembly of the repair modules outside the TO and sealifting them in.

b. Sealifting unassembled components to the TO, then assemble complete, rectangular modules with full splices between plates.

c. Reinforce plates with steel beams which protrude through damaged areas of the deck (see Reinforced Plate Subconcept in Appendix D). Do not splice between modules (Figures 8.17 and 8.18).

For subconcepts a and b, the repair is assumed to lie on top of the deck as shown in Figure 8.16a. Twelve schedule hours and 40 manhours should be added for each repair if flush mounting per Figure 8.16b is desired. Comparison results are discussed in Section 9.0.

Type B repair modules are adequate for all repair cases except a 40-ft span with CHV loading. The use of a Type A module will be an exceptional case.

An expedient pile cap may be assembled to support the midspan of the repair for Case 3 damage. Figures 8.19 and 8.20 show the configuration of the repair. A pair of W12 X 65 beams will provide support for the typical 10-ft span between piling. A 20-ft gap may be bridged by a pair of W12 X 133 beams, or a pair of W12 X 65 beams sandwiched by a 1-in. top and bottom plate. Eight scheduled hours and 24 manhours are consumed for a simple repair. A total of

50 to 100 manhours and 24 scheduled hours are consumed for a complex repair. More detail is provided in Appendix D.

Advantages to the erector set concept involve versatility. The components may be assembled in any configuration. Adjustments may be made for unforeseen circumstances. Engineer units will find other uses for the components.

The disadvantages to the erector set concept involve assembly problems. Bolting consumes most of the assembly time. Misalignment of bolt holes will be an inevitable problem. Steel erection crews have a variety of techniques and tools available to remedy misalignment problems. The use of a different fastening system, possibly copied from another expedient military device, might speed the assembly.

8.4 Steel Beam Mat Concept (see Appendix D for detailed design and comparison calculations)

A continuous mat of steel beams laid side by side could also be used as a bridge. It is assumed that the weight of a CHV is shared by at least four beams because the wheels are wide enough to bear on at least two beams each (Figure 8.23). The flanges of the beams will be about 1 ft wide. Schedule time and manhours are one-third those of the erector set full rectangular repair module concept because the beams would only have to be bolted together sufficiently enough to prevent lateral instability and shifting. One bolt per square foot was assumed to estimate manhours and schedule time. This concept would not be as flexible as the erector set concept for forming alternate repair configurations.

Using the previous assumptions, a mat of W12 X 190 beams provides approximately the same moment resistance as the 40-ft expedient bridge developed in the erector set concept. The total weight of material required for a 40- by 16-ft bridge is 121,600 lb. Maximum deflection will be approximately 2 in. The lightest steel beam which could be used for an equivalent repair is a W30 X 99. The total weight of the repair is 63,360 lb. Use of 30-in. beams is not recommended because the thickness of the repair mat would interfere with operations unless the beams could be underslung or set flush with the deck. A mat of W12 X 107 beams would be required to carry a P&H 6250-TC over a 20-ft gap.

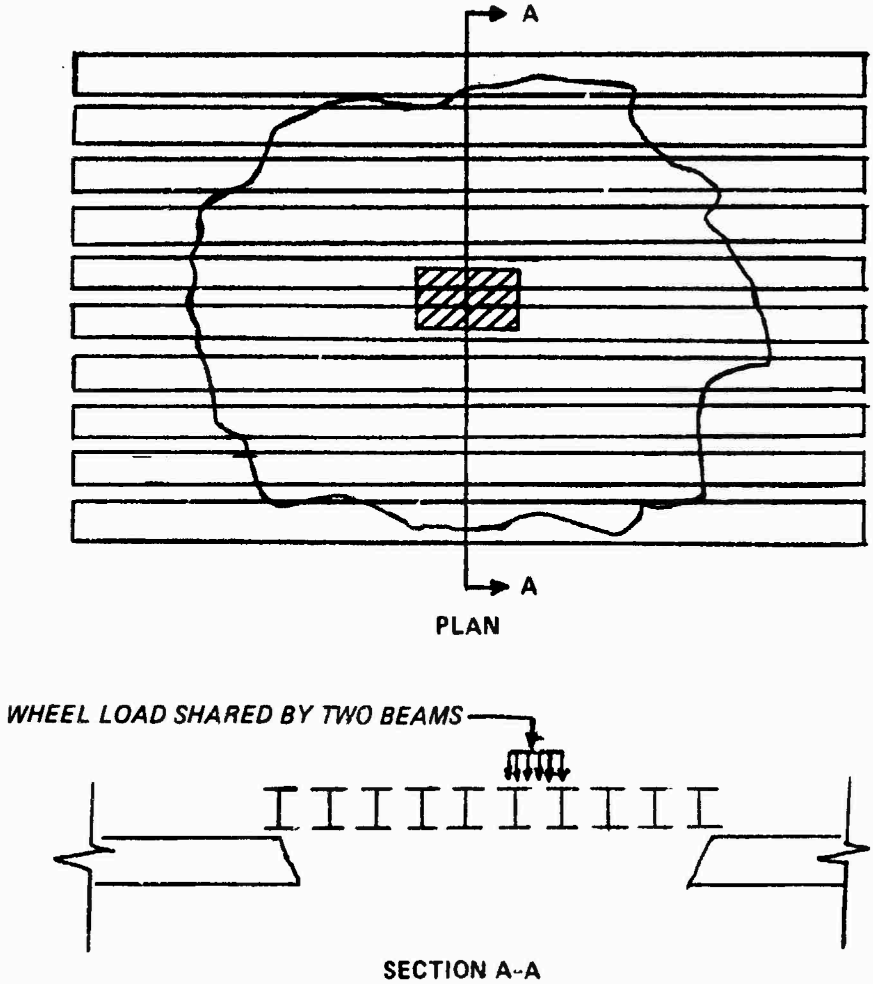


Figure 8.23. Steel beam mat concept repair

8.5 Steel Beam and Timber Deck Concept (see Appendix D for detailed design and comparison calculations)

Timber or laminated wood could be used to provide a deck for an expedient repair. Forest products may be the materials of choice because of availability within the TO.

Conventional design methods allow the use of forest products for decking and stringer for the HS 20-44 loading. This loading places about the same shear and moment demand on a structure as the Army's class 40 W loading. Steel and timber design for class 40 W loading is well documented in Reference 7.4 and other Army field manuals.

Figures 3.1 and 3.2 show two possible configurations for timber and steel repairs. During visits to PCC's, personnel showed the greatest interest in developing repairs of this type because the construction materials and methods were familiar. The repair shown in Figure 3.1 would be constructed as follows:

a. Remove unsound concrete and rebar from the edge of the crater.

b. Drill bolt holes for beam hangers through the deck with a pneumatic jackhammer or diamond coredrill.

c. Position beams under the slab. This could be done with some difficulty by passing them through the opening with a crane. An alternative would be to float them into position.

d. Install bolts and bearing plates to secure the beams.

e. Cut the timbers to fit snugly into damaged areas.

f. Install "J" bolts to secure timbers to the beams. J bolts are routinely used by railroads to secure timber ties to steel stringers.

g. Cover the repair with layers of plywood to protect protruding bolts from damage.

The result is a flush repair which will not hinder container handling operations. Disadvantages are that the edges of the crater have to be cleaned up, underslinging the beams would be difficult, and no preassembly is possible. Several different operations and several different components are required to make the repair. The repair must be custom built, which requires more supervision.

The alternative shown in Figure 3.2 was developed to answer objections to the previous alternative. Panels could be prefabricated and transported to the repair area. The panels could be laid on top of the deck over the repair

area with end ramps provided as access or, if time permitted, a flush repair could be produced by saw cutting an opening which matches the size of the panel; support could be provided by bearing assemblies attached to pile caps or the bottom of the deck. These panels could be preassembled and stockpiled before they are needed. Preassembly could also be accomplished in back areas while cleanup and sawcutting operations proceeded on the wharf.

Further research is necessary concerning design details of the panel concept. Placing loads on the bottom flange of a beam is unconventional. If only one side of the steel beam were loaded, there would be a tendency for it to twist. Sufficient horizontal crossbracing and end bracing will be required. Clamping the timbers together with beams may produce a beneficial posttensioning effect as explained in Reference 8.6. If posttensioning is used, the lumber should run parallel to the direction of the steel stringers.

The shear strength of timbers greatly limits their usefulness when operation of container handling equipment is planned. Timbers 12 by 12 in. would be convenient to use for decking material. A Cat 988 forklift would place a maximum tire print width of 35 in. on a timber. Tire pressure is 70 lb/sq in. so that a shear force of 29,400 lb is imposed on the timber. Reference 7.4 limits the shear force on a 12 by 12 timber to 14,300 lb. A timber 24 by 12 in. would be required to resist this shear force. Timbers of this size would be hard to find and the depth of the repair mat would cause operational problems for CHV's.

Allowable shear stress is limited by low shear strength parallel to the grain which is caused by the possible presence of splits in the wood near the end of the timber. This problem may be mitigated by nail or glue laminating smaller members into mats of the desired size. This process causes the load to be shared by all the wood in the mat so the presence of a defect in one member is not as serious. This is an attractive alternative because smaller members such as 2 by 12 timber are easier to obtain than big timbers. Reference 8.7 contains a complete explanation of possible uses for laminated forest products in expedient port construction. As mentioned in the discussion concerning prefabricated timber panels, posttensioning timber mats are also helpful.

Less conservative methods for calculating allowable shear stress in timber are also available. They are explained in Reference 8.8. Because of the temporary nature of the repairs contemplated by this study, larger maximum

allowable stresses may be justified in some cases. This is explained in Reference 8.9. If failures are not catastrophic, it may be wise to push the material to its limits and replace failed members from a nearby stockpile.

The possibility of crushing due to a load applied perpendicular to the grain of the wood is ignored in this report. Wood is extremely weak in this regard. This failure would cause dimensional changes which might be objectionable in permanent structures, but would not compromise the usefulness of temporary repairs. If further research shows that crushing is a problem, improvement should be made in the deck to stringer interface.

Figures 8.24 and 8.25 were developed for use as design aids for timber decks which will support CHV's. The tire print of CHV's is wide in comparison to typical stringer spacings. An overly conservative design results if wheel loads are assumed to be point loads which bear on one element of the timber deck. The figures show the required shear and moment resistance needed for a 12-in.-wide timber deck element to carry a wheel load with tire print width "b" when the tire is inflated to 1 lb/sq in.. The required shear and moment resistance is found by multiplying the value obtained from the figures by the tire pressure of the vehicle. In figuring shear stress, the span may be reduced by twice the material thickness. Reduction of tire pressure for machinery may increase the usefulness of timber decking.

Wood products may be selected from Table 7-1 in FM 5-34 (Ref 7.4), based on results from Figures 8.24 and 8.25. Shear and moment capacities may be multiplied by the number of elements required to produce a 1-ft width of deck.

Calculations in Appendix D show design assumptions which will allow use of 12- by 12-in. timbers to cover a deck supported by stringers spaced at 5 ft which may be used by CHV's.

8.6 Steel Beam and Steel Bar Grate Concept (see Appendix D for detailed design and comparison calculations)

Steel bar grate is occasionally used as a deck material on draw bridges. It could be used to replace timber decks for expedient repair purposes. An equivalent repair which is made with bar grate instead of timber will require the same or more shipping tonnage and less shipping cubage. Bar grate has only one way structural resistance, and composite action cannot be developed

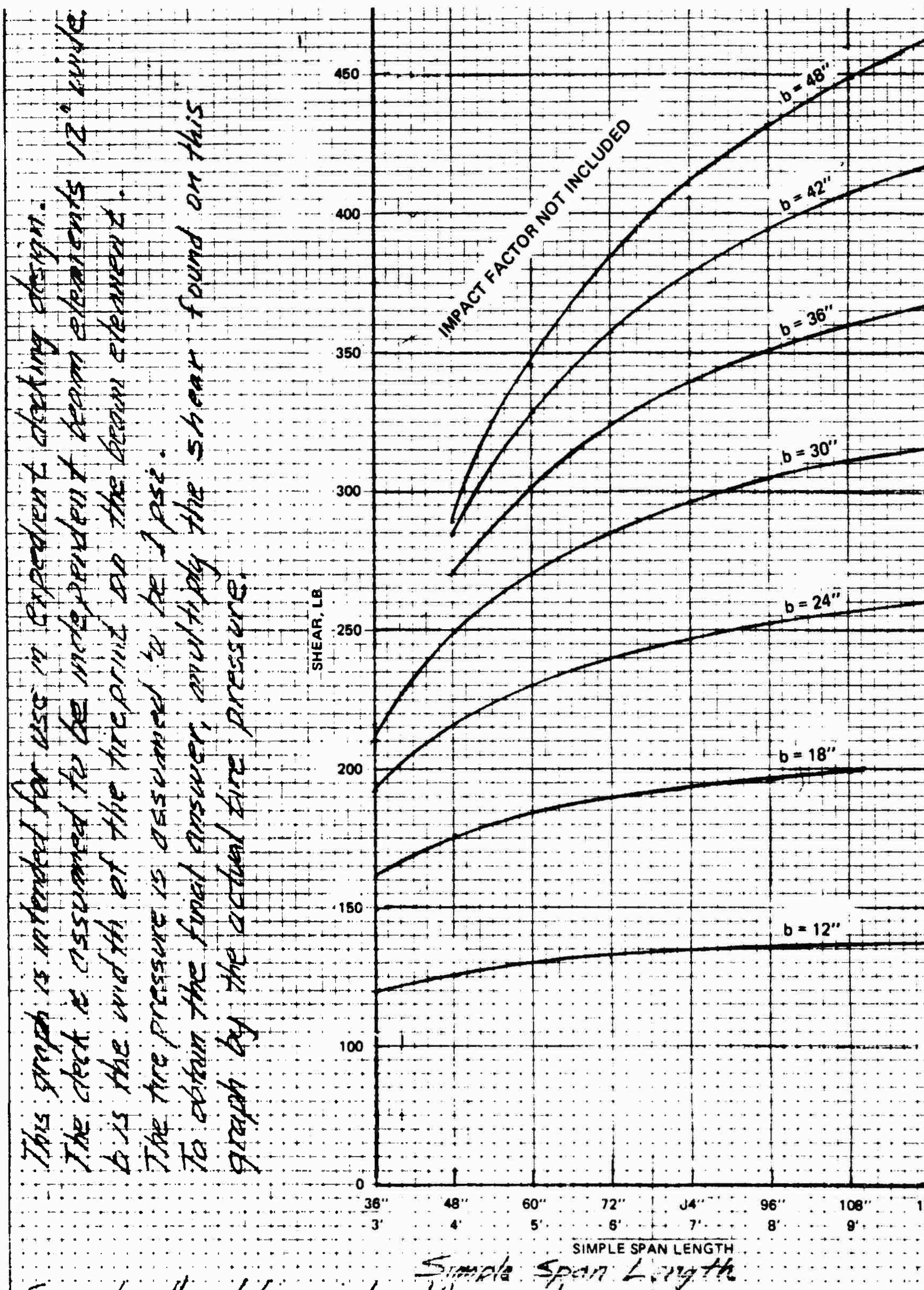


Figure 8.24. Shear diagram for timber deck

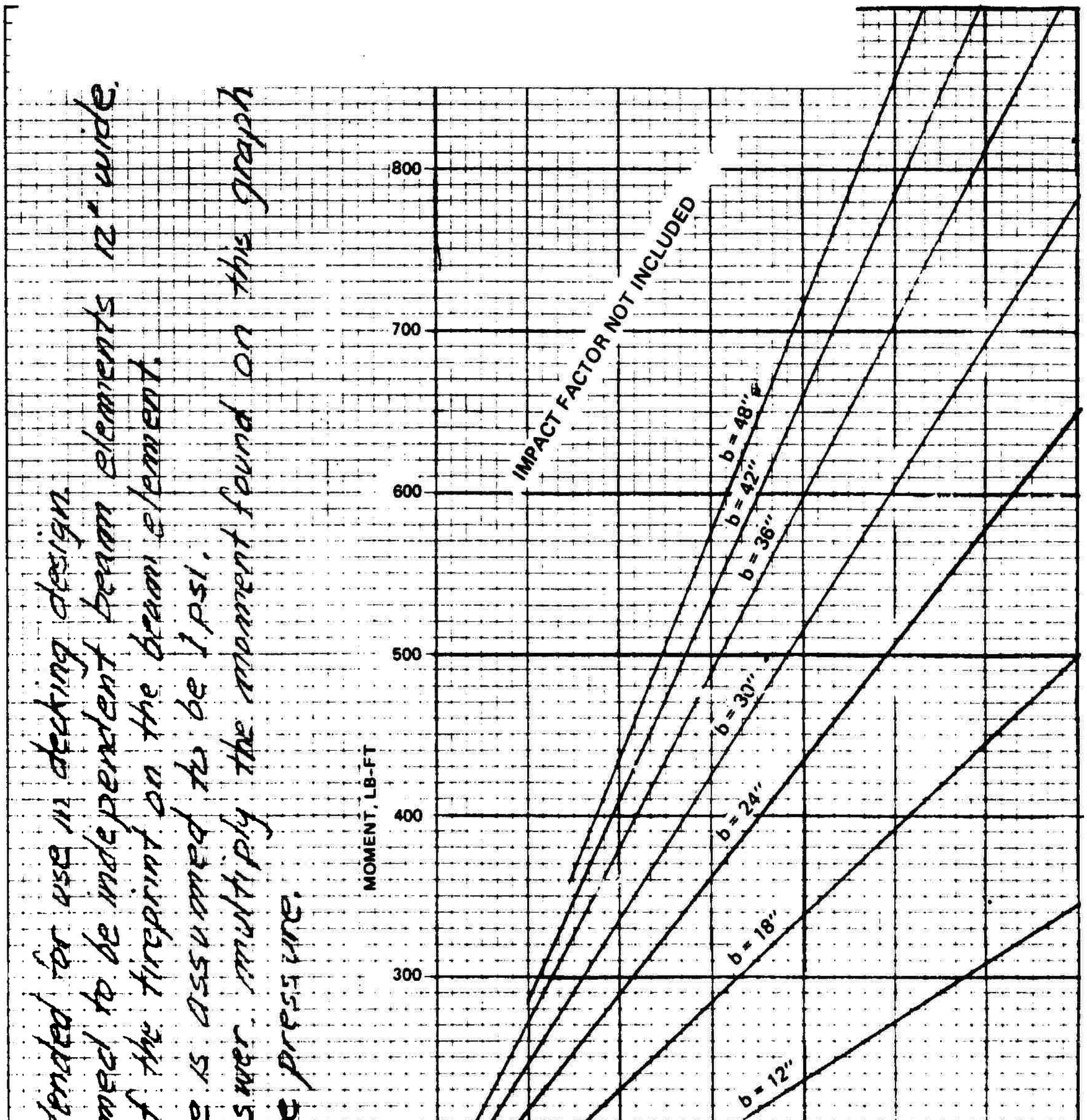


Figure 8.25. Moment diagram for timber deck

between the bar grate and supporting beams. Bar grates can carry CHV's over 2- to 6-ft spaces between supporting beams. A 6-ft beam spacing would require a grate made from 7- by 1/2-in. bar stock spaced at 2-3/8 in. on center, which weighs 70 lb/sq ft. A 2-ft beam spacing would require a grate made with 3- by 1/4-in. bar stock spaced at 2-3/8 in. on center which weighs 17.7 lb/ sq ft. A grate which is 7 in. deep and weighs 52.7 lb/sq ft could carry the HS 20-44 load over the 8.4 ft diam crater specified in the original scenario. A 7-in. deep grate which weighs 130 lb/ sq ft could span 17 ft with an HS 20 load. One manufacturer, Engineer Grating, Inc., of Houston, Tex., suggests a maximum span of 10 ft because of deflection problems and a maximum allowable stress of 20 ksi. Because of the temporary and expedient nature of the repairs proposed by the report, it may be possible to relax these maximums.

Telephone conversations with a bar grate manufacturer indicate that grates which are deeper than 4 in. or which have bars thicker than 3/8 in. must be handmade. Machine made grates cost $0.75 to $1.00/lb. Handmade grates are $1.00 to $1.50/lb. The 2- by 8-ft modules are recommended for ease of handling.

8.7 Prestressed Concrete Girders (see Appendix D for detailed design and comparison calculations)

Prestressed concrete slabs and box beams would be most useful when custom-made for a certain wharf and stored nearby. After a prestressed girder has been cast, it is impossible to modify it by trimming if it is in the field. The beams must be handled carefully because they will crack if they are not set and lifted in a manner that is compatible with their design.

If a precasting plant were available near the port, prestressed beams could be cast and cured in 7 days. If high strength concrete is used, the beams cure to required strength sooner. Given favorable circumstances and by adding special admixtures to the concrete, beams may be ready for use 24 hr after casting. Since the fatigue life of these beams may be questionable, caution and engineering judgement should be exercised before the beams are used. Studies are now in progress at Purdue University concerning design improvements that may be made when high strength concrete is used for prestressed girders.

Use of prestressed beams would be most appropriate on a structure which only experiences HS 20-44 loading. That is because standard prestressed beam configurations were designed to carry truck loads on bridges.

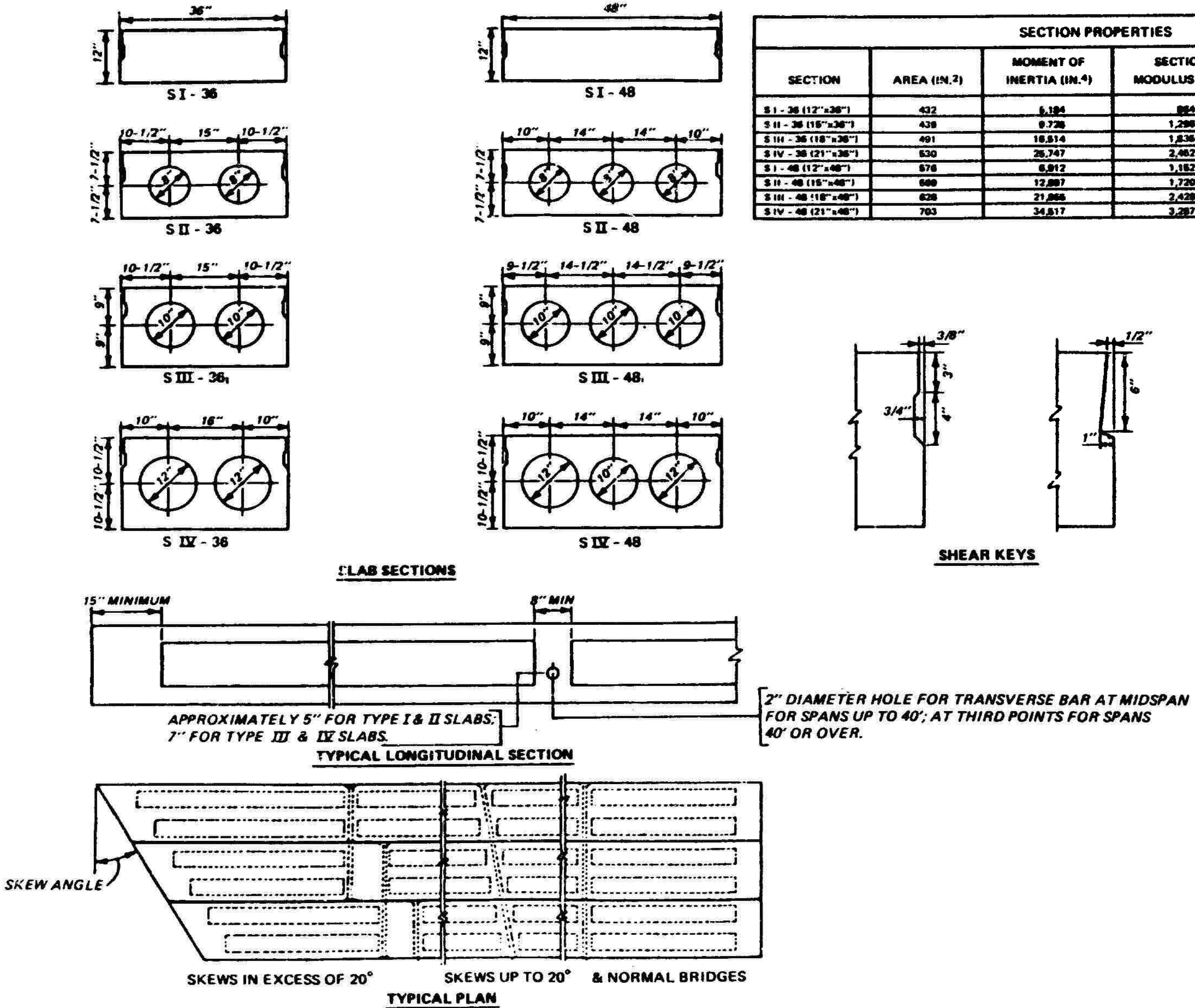
Standard beam designs have been developed by a joint committee of the American Association of State Highway and Transportation Official (AASHTO) and the Prestressed Concrete Institute (PCI). These include slab sections from 12 to 21 in. thick (Figure 8.26), box beams from 27 to 42 in. deep, and beams from 2 ft 4 in. to 6 ft deep (Figure 8.27). Use of prestressed slabs would be most appropriate for structures which carry only HS 20-44 loads. Box beams have more moment capacity, and the top surface will also serve as the deck for the wharf. A 42-in.-deep beam can be designed to span 100 ft. Moment demand for an HS 20-44 loading at 100 ft exceeds that of the P&H 6250-TC on a 20-ft span (Figures 5.2 and 5.8). Shear demand is much greater for CHV's on a 20-ft span than a truck on a 100-ft span (Figures 5.1 and 5.9). Based on the foregoing, it is concluded that a 42-in. box beam would carry container handling equipment over a 20-ft span, if shear resistance was improved. The loss of dead load due to the shorter span length is ignored; therefore, this analysis is conservative.

Standard bridge beams are designed with the assumption that a concrete deck will be placed on top of them that will act as a compression flange. Since extensive use of cast-in-place concrete is not considered in this study, the use of standard bridge beams is not recommended.

Conversations with a prestressed concrete plant operator indicate that the price of $425/cu yd may be used for conceptual estimates on prestressed concrete beams.

8.8 Railroad Flatcars

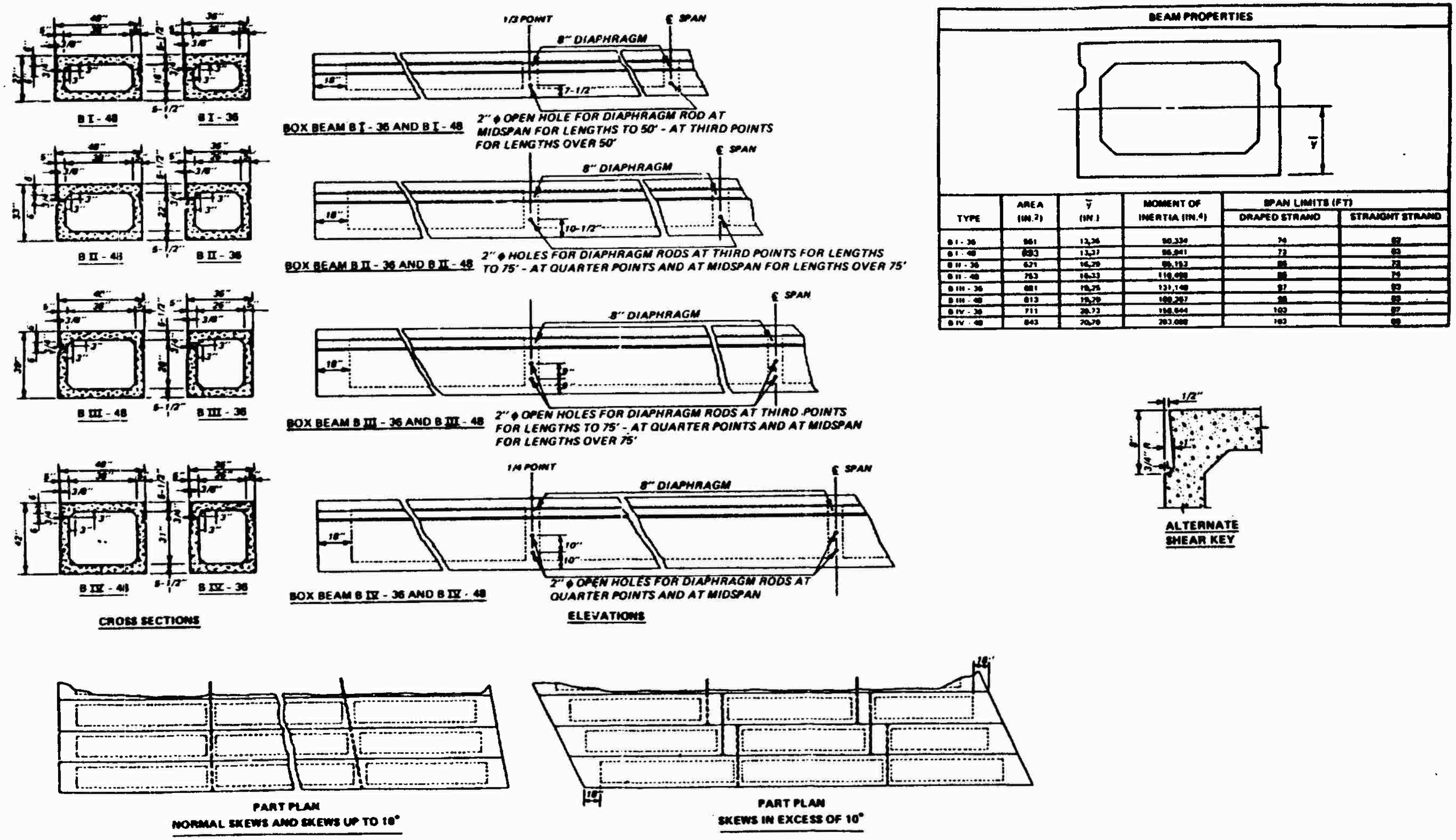
Railroad flatcars are designed to carry trucks when used in intermodel (piggyback) service. A typical piggyback 9-ft-wide flatcar is 9 ft wide and 90 ft long and spans 66 ft between truck centers. It is recommended that the cars be taken off their trucks and mounted on bearing assemblies that simulate the truck centers and rest on the undamaged portion of the deck. The use of end ramps will be necessary. The structure should be able to withstand HS 20-44 load with no difficulty.



SECTION PROPERTIES

SECTION	AREA (IN.^{2})	MOMENT OF INERTIA (IN.^{4})	SECTION MODULUS (IN.^{3})	APPROXIMATE SPAN (FT) H20-S16-44	H20-44
S I - 36 (12"x36")	432	5,184	864	20-28	20-29
S II - 36 (15"x36")	439	9,725	1,296	27-36	28-38
S III - 36 (18"x36")	491	16,514	1,835	34-42	37-46
S IV - 36 (21"x36")	530	25,747	2,452	41-49	46-54
S I - 48 (12"x48")	576	6,912	1,152	20-28	20-29
S II - 48 (15"x48")	569	12,897	1,720	27-35	28-38
S III - 48 (18"x48")	628	21,855	2,428	34-42	37-46
S IV - 48 (21"x48")	703	34,517	3,287	41-50	46-56

Figure 8.26. AASHTO/PCI standard slabs (from AASHTO/PCI joint standards for concrete bridge slabs)



TYPE	AREA (IN.²)	$\bar{y}$ (IN.)	MOMENT OF INERTIA (IN.⁴)	SPAN LIMITS (FT) DRAPED STRAND	SPAN LIMITS (FT) STRAIGHT STRAND
B I - 36	561	12.36	50,334	74	92
B I - 48	693	13.37	56,941	72	93
B II - 36	621	16.29	95,152	88	73
B II - 48	753	16.33	110,499	86	74
B III - 36	681	18.25	131,140	97	93
B III - 48	813	19.29	169,267	98	93
B IV - 36	711	20.73	158,644	103	97
B IV - 48	843	20.79	203,088	103	99

Figure 8.27. AASHTO/PCI standard concrete box beams (from AASHTO/PCI)

CHV's might also be accommodated if two railroad cars are laid side by side and the vehicle is driven with one on each railroad car. Telephone conversations with railroad car owners indicate that the cars are designed to be stressed to their yield limit divided by 1.8 and that the cars are usually made with 50-ksi steel. Figure 5.8 shows that the moment demand for an AASHTO truck loading on a 65-ft span without the impact factor is about 950 ft-kips. Multiplying 950 by 2 and 1.8 will give a rough estimate of the capacity of two flat cars at their yield limit. The resulting capacity is 3,420 ft-kips. This is sufficient to carry a CAT 988 over the full span length or a P&H 6250-TC over a 40-ft span (see Figure 5.5).

9.0 Results of Comparisons

Tables 9.1, 9.2, 9.3, and 9.4 compare schedule hours, manhours, shipping cubage, and acquisition cost for using each repair method on a typical damaged berth. Tables 9.1 and 9.2 present typical damaged berth repair information for each repair method (i.e., Case 1 plus Case 2 plus Case 3 damage). Tables 9.3 and 9.4 present repair information using the repair method shown for Case 3 damage plus steel plate repairs used for Case 1 and Case 2 damage. Several qualitative items are also compared. Section 8.1 contains a complete explanation.

The results of the comparisons show that a typical damaged berth could be repaired in 48 hr using steel plates for Case 1 and 2 damage and steel beam mats or preassembled erector set modules for Case 3 damage. This assumes two 10-hr shifts per day and 10 man crews. A crane capable of lifting 40,000 lb at a 30-ft radius and a flatbed truck will be required. Minimal bolting, steelcutting, and welding are required. No concrete removal is required except to provide a flat deck surface on which to lay repair components. Shipping cubage will be equivalent to one-half to three-quarters of a 40-ft container. Shipping weight will be between 100 and 110 tons. Acquisition cost is between $100,000 and $150,000. Of the repair concepts studied, steel plate and beam repairs require the least schedule time.

In general, the use of steel plates to repair Case 1 and Case 2 damage results in a shorter schedule, fewer manhours, reduced shipping cubage, and fewer qualitative restrictions when compared with repair of all damage with one method.

Table 9.1. Comparison of Repair Techniques (Design load: HS 20-44/1,000 lb/sq ft)

TABLE 9.1. COMPARISON OF REPAIR TECHNIQUES
DESIGN LOAD: HS 20-44 / 1,000 LB/SQ FT

REPAIR SYSTEM		SCHEDULE HOURS	MAN HOURS	SHIPPING CUBAGE CU/FT	SHIPPING WEIGHT 1000 LB	AQUISITION COST $1000	MAX LIFT REQ'D KIPS	SHOP FABRICATION REQUIRED?	PREFABRICATION POSSIBLE IN T.O.?	FLUSH REPAIR CAPABILITY?	PREPOSITIONING REQUIRED?	CRANE REQUIRED?	COMPONENTS CAN BE DRAGGED?	EXTENSIVE CONCRETE REMOVAL REQUIRED?
ERECTOR SET CONCEPT	MODULES ASSEMBLED IN TO	240	2400	1600	260	260	8' x 40' MODULE 40K	Y	Y	W	H	H	N	F
	PREASSEMBLED MODULES	65	560	4100	260	200		Y	N/A	W	H	H	N	F
	STEEL L'S REINFORCED WITH STEEL BEAMS	120	480	570	160	200		H	N	Y	H	N	N	N
STEEL BEAM MAT CONCEPT		63	780	1200	80	40	W12x190 40' LONG 7.6K	H	Y	W	H	N	Y	F
STEEL BEAM CONCEPT	TIMBER DECK	200	1200	2400	130	40	W12 x 190 40' LONG 7.6K	N	Y	Y	H-N	H	Y	Y
	BAR GRATE DECK	↓	↓	1600	130	60		Y	Y	Y	H	H	Y	Y
	DECK OBTAINED IN T.O.	↓	↓	1200	60	30		N	N	Y	H-N	H	Y	Y
PRECAST, PRESTRESSED CONCRETE BEAMS		200	940	3100	410	40	BOX BEAM 3.5 x 3 x 40' 33K	Y	W	Y	Y	Y	N	Y

ABBREVIATIONS: Y = YES; N = NO; H = HELPFUL, BUT NOT REQUIRED; W = YES, BUT EXTRA WORK REQUIRED; F = REQUIRED FOR FLUSH REPAIR, BUT NOT OTHERWISE.

Table 9.2. Comparison of Repair Techniques (Design load: CHV (Cat 988/P&H 6250-TC))

TABLE 9.2. COMPARISON OF REPAIR TECHNIQUES
DESIGN LOAD: CAT 988, P&H 6250-TC

Concept	Repair System	Schedule Hours	Man Hours	Shipping Cubage CU/FT	Shipping Weight 1000 LB	Aquisition Cost $1000	Max Lift Req'd Kips	Shop Fabrication Required?	Prefabrication Possible in T.O.?	Flush Repair Capability?	Prepositioning Required?	Crane Required?	Components Can Be Dragged?	Extensive Concrete Removal Required?
Erector Set Concept	Modules Assembled In To	240	2400	1800	300	300	8' x 40' Module 40K	Y	Y	W	H	H	N	F
	Preassembled Modules	65	580	4200	300	220		Y	N/A	W	H	H	N	F
	Steel ℄'s Reinforced With Steel Beams	120	480	600	200	200		H	N	Y	H	N	N	N
Steel Beam Mat Concept		80	800	1900	160	80	W12 x 190 40' Long 7.6K	H	Y	W	H	N	Y	F
Steel Beam Concept	Timber Deck	200	1200	2800	140	50	W12 x 190 40' Long 7.6K	N	Y	Y	H-N	H	Y	Y
	Bar Grate Deck	↓	↓	2150	200	150		Y	Y	Y	H	H	Y	Y
	Deck Obtained In T.O.	↓	↓	1500	70	30		N	N	Y	H-N	H	Y	Y
Precast, Prestressed Concrete Beams		200	940	8600	800	80	Box Beam 3.5 x 3 x 40' 33K	Y	W	Y	Y	Y	N	Y

Abbreviations			
	Y - YES	H - HELPFUL, BUT NOT REQUIRED	F = REQUIRED FOR FLUSH REPAIR, BUT NOT OTHERWISE.
	N - NO	W = YES, BUT EXTRA WORK REQUIRED	

Table 9.3. Comparison of Repair Techniques

TABLE 9.3. COMPARISON OF REPAIR TECHNIQUES
DESIGN LOAD: HS 20-44, 1000 PSF, REPAIR SYSTEM USED FOR CASE 3 DAMAGE ONLY. ALL OTHER COVERED WITH STEEL PLATE.

	REPAIR SYSTEM	SCHEDULE HOURS	MAN HOURS	SHIPPING CUBAGE CU/FT	SHIPPING WEIGHT 1000 LB	AQUISITION COST $1000	MAX LIFT REQ'D KIPS	SHOP FABRICATION REQUIRED?	PREFABRICATION POSSIBLE IN T.O.?	FLUSH REPAIR CAPABILITY?	PREPOSITIONING REQUIRED?	CRANE REQUIRED?	COMPONENTS CAN BE DRAGGED?	EXTENSIVE CONCRETE REMOVAL REQUIRED?
ERECTOR SET CONCEPT	MODULES ASSEMBLED IN TO	78	680	880	220	140	8' x 40' MODULE 40K	Y	Y	W	H	H	N	F
	PREASSEMBLED MODULES	45	340	1500	220	130		Y	N/A	W	H	H	N	F
	STEEL L'S REINFORCED WITH STEEL BEAMS	54	360	660	220	140		H	N	Y	H	N	N	N
STEEL BEAM MAT CONCEPT		46	450	990	200	100	W12 x 190 40' LONG 7.6K	H	Y	W	H	N	Y	F
STEEL BEAM CONCEPT	TIMBER DECK	56	580	1200	230	100	W12 x 190 40' LONG 7.6K	N	Y	Y	H-N	H	Y	Y
	BAR GRATE DECK			980	230	110		Y	Y	Y	H	H	Y	Y
	DECK OBTAINED IN T.O.			850	200	100		N	N	Y	H-N	H	Y	Y
PRECAST, PRESTRESSED CONCRETE BEAMS		71	400	2000	440	120	BOX BEAM 3.5 x 3 x 40' 33K	Y	W	Y	Y	Y	N	Y

ABBREVIATIONS		
Y = YES	H = HELPFUL, BUT NOT REQUIRED	F = REQUIRED FOR FLUSH REPAIR, BUT NOT OTHERWISE.
N = NO	W = YES, BUT EXTRA WORK REQUIRED	

Table 9.4. Comparison of Repair Techniques

TABLE 9.4. COMPARISON OF REPAIR TECHNIQUES
DESIGN LOAD: CAT 988, P&H 6250-TC
REPAIR SYSTEM USED FOR
CASE 3 DAMAGE ONLY.
ALL OTHER COVERED WITH
STEEL PLATE.

REPAIR SYSTEM		SCHEDULE HOURS	MAN HOURS	SHIPPING CUBAGE CU/FT	SHIPPING WEIGHT 1000 LB	AQUISITION COST $1000	MAX LIFT REQ'D KIPS	SHOP FABRICATION REQUIRED?	PREFABRICATION POSSIBLE IN T.O.?	FLUSH REPAIR CAPABILITY?	PREPOSITIONING REQUIRED?	CRANE REQUIRED?	COMPONENTS CAN BE DRAGGED?	EXTENSIVE CONCRETE REMOVAL REQUIRED?
ERECTOR SET CONCEPT	MODULES ASSEMBLED IN TO	78	680	1100	260	180	8' x 40' MODULE 40K	Y	Y	W	H	H	N	F
	PREASSEMBLED MODULES	45	340	1500	260	155		Y	N/A	W	H	H	N	F
	STEEL ℄'S REINFORCED WITH STEEL BEAMS	54	360	690	260	180		H	N	Y	H	N	N	N
STEEL BEAM MAT CONCEPT		48	450	1100	240	120	W12 x 190 40' LONG 7.6K	H	Y	W	H	N	Y	F
STEEL BEAM CONCEPT	TIMBER DECK	56	575	1500	230	100	W12 x 190 40' LONG 7.6K	N	Y	Y	H-N	H	Y	Y
	BAR GRATE DECK			1300	250	150		Y	Y	Y	H	H	Y	Y
	DECK OBTAINED IN T.O.			1100	200	100		N	N	Y	H-N	H	Y	Y
PRECAST, PRESTRESSED CONCRETE BEAMS		71	400	3400	440	160	BOX BEAM 3.5 x 3 x 40' 33K	Y	W	Y	Y	Y	N	Y

ABBREVIATIONS

Y - YES | H - HELPFUL, BUT NOT REQUIRED
N - NO | W - YES, BUT EXTRA WORK REQUIRED

F = REQUIRED FOR FLUSH REPAIR, BUT NOT OTHERWISE.

The plate concept requires no shop fabrication, no crane service (plates may be dragged into position with a large vehicle), and no extensive concrete removal. The PCC cranes may easily handle the maximum lift requirement of 12,800 lb for a 20-ft by 8-ft by 2-in. steel plate. The schedule time is determined by the speed that the plates can be selected from a stockpile, transported to the repair area, set in place, and secured from sliding.

Shipping weight and acquisition costs are generally increased when plates are used; however, in an emergency sealift situation these disadvantages are not important. In consideration of the previously mentioned advantages, steel plate should be a high priority material in future port repair systems.

The steel beam mat concept is an attractive repair method because of its short schedule time and low acquisition cost. The schedule is controlled by schedule time as is the case with steel plates. The manhour requirement could be reduced if a method for securing the beams without bolts was developed.

Erector set modules assembled in the TO appear unattractive in all categories except shipping cubage. Bolting time and fabrication costs result in a poor showing in time and cost categories. Since this concept has high flexibility, two other subconcepts were considered: preassembly of the modules and reinforcing the steel plates with beams in the crater area only. Preassembly of the units results in greatly reduced schedule time and manhours but greatly increased shipping cubage. All comparison categories are improved when the steel plate concept is used. Most significant is manhours because bolting is held to an absolute minimum.

The use of steel beams in combination with timber deck results in a 10-day repair schedule. Manhours and shipping cubage are in the middle of the range; acquisition cost and shipping weight are lower. Shipping cubage is reduced when steel bar grate is substituted as a deck material, but shipping weight and acquisition cost is increased if the repair must withstand CHV loads. This is because thick, handmade grates are required for heavy loads, and light machine-made grates are satisfactory for smaller loads.

If deck materials are available in the TO, they do not need to be sealifted. This results in significant reductions in shipping weight and shipping cubage, as shown in the tables.

The use of prestressed beams results in high shipping cubage and shipping weight, especially for CHV loading. This is because 3.5- by 3-ft box beams

are required for CHV loading while 12- and 21-in. slabs are sufficient for HS 20-44 loads.

In general, comparison of CHV loading (Tables 9.2 and 9.4) with 1,000 lb/sq ft/HS 20-44 loading (Tables 9.1 and 9.3) results in slight increase in shipping cubage and shipping weight but has an insignificant impact on schedule time and manhours.

Heavier structural sections are often required for CHV loading which may not be available in stock at local warehouses.

Examination of the qualitative comparisons highlights advantages and disadvantages between concepts. The steel beam mat concept is attractive because there are few qualitative restrictions. Handling restrictions exist for the erector set concept because rough handling may bend components and cause bolt-hole alignment problems. Steel beams with timber or bar grate decks require no special handling, fabrication, or lifting requirements; however, extensive concrete removal is required. If a crane is not available to pass underslung beams through craters during installation, the beams may be floated in on rafts. Therefore, a crane is not required for this concept.

Concrete beams have many qualitative disadvantages in addition to their undesirably high shipping cubage and shipping weight. Prestressed concrete beams are usually built in a fabrication yard and must be handled carefully to prevent damage. Also, their size and weight make them awkward to hoist and place.

10.0 Conclusions

The following conclusions are drawn from this study:

a. The loads on wharves caused by modern container methods are much greater than the loads caused by previous port operations or the loads imposed by trucks on highway bridges. Repairs for container wharves will have to be much stronger than repairs for other structures.

b. Many ports are not designed for the use of CHV's on the wharf. Instead they rely on rail mounted cranes to load trucks directly. The containers are then hauled to back areas where CHV's operate. In these cases, the strength of repairs should match the strength of the wharf. Any extra effort to provide stronger repairs would be wasted. It is unlikely that repairs to present-day container wharves will have to resist CHV loads.

c. The Navy is upgrading its pier designs. In the future, a typical Navy pier may very likely accommodate CHV's. Therefore, it is necessary to develop repairs for CHV loads.

d. The structural safety of a damaged deck may be conservatively estimated by the use of simple engineering calculations.

e. Steel is the best material to make repair kits for sealift to the TO. This is because of its high structural value in comparison to its shipping cubage. Structural steel is also easy to purchase, fabricate, and field modify. Finally, its high ductility makes it a forgiving repair material.

f. Steel beams (W sections) which weigh less than 100 lb/ft and steel plates less than 2 in. thick are available in major US ports at local warehouses. Heavier beams, thicker plates, and high strength steel require special orders.

g. Repair systems which consist of steel plates and steel beams minimize requirements for schedule time, manhours, and shipping cubage.

h. The erector set concept offers the greatest flexibility in repair configuration, but requires trade offs in schedule time, manhours, shipping cubage, and acquisition cost.

i. It is possible to use 12-in. wood deck to support CHV's with a 5-ft maximum stringer spacing.

j. Timber in small dimensions, such as 2 by 12 in. and 4 by 4 in., less than 12 ft long are available at lumber yards. The 12- by 12-in. timbers, poles, and laminated wood products require special orders.

k. Prestressed concrete beams may be useful if they are custom made for a particular pier. Prestress beams may not be modified for length, and shipping weight and shipping cubage are extremely high.

l. A pair of railroad flat cars designed for intermodel (piggyback) service may be used as an expedient bridge for certain CHV's including the Cat 988.

m. Damaged concrete may be expediently removed by using diamond saws and a hydraulic ram pavement breaker mounted on a backhoe.

n. Repair components may be connected to undamaged concrete using anchor bolts which lock into predrilled holes.

o. As of now, the PCC's are able to perform light marine construction work. They could also perform simple repairs with reduced efficiency. They do not have the ability to install heavy repair systems quickly.

p. With proper training and additional equipment the PCC's could perform heavy port repair work at top efficiency.

q. Many heavy structural items which are required for efficient port repair must be obtained on a special order basis. A policy of stockpiling these materials will be necessary to provide prompt shipments of repair components in emergency situations.

11.0 Recommendations

The following recommendations are made as a result of this study:

a. A combination of the steel plate concept and steel beam mat concept should be used when schedule time, manhours, and shipping cubage are critical. Some of the repair components should have a system of matching bolt holes which allow for flexible assembly.

b. Standard repairs using timber and concrete should be developed for situations where these materials are locally available. Wartime steel shortages and worker preference may also dictate the use of alternate materials.

c. When materials must be acquired on an emergency basis, designs should specify lightweight steel section and small dimension timber (see Section 10.0 f and j).

d. When heavy steel, large dimension lumber or shop fabrication are required, components must be stockpiled and/or prepositioned (see Section 10.0 f and j).

e. The PCC equipment allowance should include a crane with a commercial land rating of 100 tons. The equipment allowance should also include a barge that the crane can be placed on when the structure being repaired cannot withstand the crane load.

f. The PCC equipment allowance should include lightweight diamond saws and improved pavement breakers for concrete removal.

g. Standard methods should be developed for attaching steel to concrete. Lightweight drills should be included in the PCC equipment allowance.

h. PCC's should increase training emphasis on heavy lifting, steel cutting, bolting, welding, concrete cutting, and concrete removal. A cadre of expert crane operators, barge operators, and crew leaders should be carefully groomed.

i. Simulated training missions should be performed on piers which are damaged or scheduled for demolition.

j. The PCC's should participate in testing and evaluating new port repair systems.

k. The Army training literature should include the following:

(1) Standard procedures for determining structural requirements for container port repairs.

(2) Standard procedures for determining the structural adequacy of a damaged deck.

(3) Standard repairs using steel, forest product, and concrete.

(4) Information on stockpiled and preposition repair systems.

(5) Material which will stimulate innovative group sessions concerning the use of salvaged material.

12.0 Final Summary

The expedient repair of container handling ports is a unique problem because design loads are extremely high, much higher than loads for familiar structures such as highway bridges or buildings. Repairs must be completed in the shortest possible time and requirements for sealift cubage and manhours must be minimized. Finally, the repair system must be strong and compact.

Comparison of several repair concepts indicates that a system of steel plates and beams minimizes schedule time, manhours, and shipping cubage. A 1,000-ft-long typical damaged berth could be repaired within 48 hr after repair components arrive. Two crews of ten men, one crane, and one flatbed truck would be required. One crew would work a 10-hr day shift; the other would work a 10-hr night shift. Typical damage is caused by 500 lb bombs which explode on impact and leave 12 craters which average 8.4 ft in diameter. The typical berth is an open pile wharf with a 12-in.-thick concrete deck.

General wartime shortages of steel, local availability of other materials, and worker training may dictate the use of alternate materials. Lumber may be used to build decks supported by steel beams. Custom-made concrete beams could be prepositioned near important ports, ready for use. Extra schedule time and manhours will be required to complete repairs; these problems must be weighed against the problems of locating scarce materials and sealifting.

The military construction units which are responsible for the port repair are the PCC's. A PCC is informally called a "mini battalion" because of the diverse nature of its assignments, high mobility, and high ratio of officers to enlisted men. The company's equipment allowance is similar to that of a small bridge contractor. Significant pieces of equipment are loaders, flatbed trucks, forklifts, a few barges, and several cranes. The largest crane has a commercial rating of 40 tons. Training emphasizes light timber marine construction and the development of combat and teamwork skills.

The PCC's equipment and training emphasis should be shifted toward skills required for container port repairs. These include heavy lifting, steel cutting, bolting, welding, concrete cutting, and concrete drilling. Larger cranes, work barges that will accommodate the cranes, and lightweight concrete saws and drills should be added to the PCC equipment allowance. Future training exercises should include repair of simulated damage on piers scheduled for

demolition. The PCC's should participate in the test and evaluation of future repair systems.

Changes should also be considered in the design and construction of new ports. Structures should be built strong enough to accommodate CHV's in case a rail-mounted crane is disabled. The structure could be designed for quick repair, and replacement components could be stored nearby.

The repair of existing ports would be expedited by the development of contingency repair plans and prepositioned repair components.

The cost of port repair systems is modest when the benefits are considered. Major port facilities which handle critical supplies bound for forward areas would be restored to operation sooner. Using the typical damaged berth as a standard for comparison, the cost of heavy steel repair components is \$100,000 to \$150,000, and the schedule time is 2 days. Equivalent timber or concrete repairs would cost about \$30,000 and would require about 8 to 10 days to complete.

Reduced port repair time will increase the speed and volume of shipments and will enhance logistical support for troops in conflict areas.

13.0 References

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5.2. Department of the Navy, "Piers and Wharves, Design Manual 25.1," NAVFAC DM-25.1, Naval Facilities Engineering Command, Alexandria, Va., Nov 1980.

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6.1. Wallace, M., "Concrete Saw and Drills: What Can They Do? When Are They Useful?" Concrete Construction, Sep 1985, pp 743-745.

6.2. Concrete Construction, "Pavement and Parking Deck Demolition," Apr 1982, p 368.

6.3. Concrete Construction, "Nonexplosive Demolition of Concrete and Rock," Apr 1982, p 366.

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7.1. Headquarters, Department of the Army, "Army Transportation Container Operations," FM 55-70, Feb 1975.

7.2. Godfrey, K. A., Jr., "High Strength Steel: Crisis of No?" Civil Engineering/ASCE, May 1965, pp 50-53.

7.3. Helmke, Richard W., Booth, Graham, and Hug, Bruno, "Trilateral Design and Test Code for Military Bridging and Gap-Crossing Equipment," Jan 1984.

7.4. Headquarters, Department of the Army, Engineer Field Data, FM 5-34, 1976.

8.1. Departments of the Army, the Navy, and the Air Force, Moving, Rigging Handbook, Army TB 420-16, NAVFAC P-709.0, Air Force AFM 85-48, Apr 1981.

8.2. Naval Facilities Engineering Command, Seabee Planner's and Estimator's Handbook, NAVFAC P-405, Oct 1983.

8.3. Robert Snow Means, Inc., Building Construction Cost Data, 1983, 1984, and 1985 editions, Kingston, Mass.

8.4. American Institute of Steel Construction, Manual of Steel Construction, 8th edition, Chicago, Ill.

8.5. Errera, Samual J., "Material," Ch. 2, Structural Steel Design, 2nd edition, Lambert Tall, ed., Ronald Press, New York, 1974.

8.6. Civil Engineering/ASCE, "Timber Bridge Decks," May 1985, p 47.

8.7. Clark, A. A., et al., "Port Construction in the Theater of Operations," US Army Engineers Waterways Experiment Station, TR H-73-9, Vicksburg, Miss., Jun 1973.

8.8. Gurfinkel, German, "Wood Engineering, Southern Forest Products Association," New Orleans, La., 1973, pp 212-221.

8.9. Hoyle, Robert J., Jr., "Wood Technology in the Design of Structures," 4th edition, Mountain Press, Missoula, Mont., 1978.

APPENDIX A

BIBLIOGRAPHY

BIBLIOGRAPHY

The following reports, which have recently been completed under the direction of the Naval Civil Engineering Laboratory, address expedient port repair topics:

Naval Civil Engineering Laboratory Reports

"Advanced Technology Container Handling in Damaged Mideast Ports," Naval Civil Engineering Laboratory, TM 55-84-05CR, Jul 1984.

This report covers possible disruption scenarios, damage assessment, and damage repair. Conceptual repair methods for open pile piers and quay walls are included. Dock beams which were proposed by this report are illustrated in Figures A1 and A2.

Harvey Haynes and Associates, "Concept Study of Rapid Construction Method for Piers at Advanced Bases," Naval Civil Engineering Laboratory, Report for contract No. N62583/83MT353, Jan 1984.

This report discusses how a pile driving templates known as "Mini Jackets" and segmental construction methods may be used to build long piers and bridges without the aid of floating construction equipment transportability, cost, construction time, and possible uses.

Naval Civil Engineering Laboratory, "Mobile Crane Handbook for Expedient Cargo Handling Operations," Dec 1983.

This report covers the use of mobile cranes for container discharge when other unloading devices are unavailable. The mobile cranes discussed are commercially available truck and crawler lift cranes with lattice-type booms. Topics of special interest include cranes for existing dock facilities and cranes for temporary piers. Figure A3 shows a pair of hatch cover bridging beams which could support a crane on the deck of a container ship. Extensive crane selection information appears in the appendixes.

Naval Facilities Engineering Command, "Integrated Logistic Support Plan for Elevated Causeway Restore Span," NAVFAC ILSP0309, May 1985.

This report is a proposal for a lightweight temporary bridge which could be used to restore a damage elevated causeway. The span is transported to the site in container compatible racks and positioned using an end launch process (see Figures A4 and A5).

Other Reports

The following documents were especially helpful in preparing this report:

Clark, A. A., et al. "Port Construction in the Theater of Operations," US Army Waterways Experiment Station, TR H-73-9, Jun 1973.

Headquarters, Department of the Army. "Port Construction and Rehabilitation," TM 5-360, Sep 1964.

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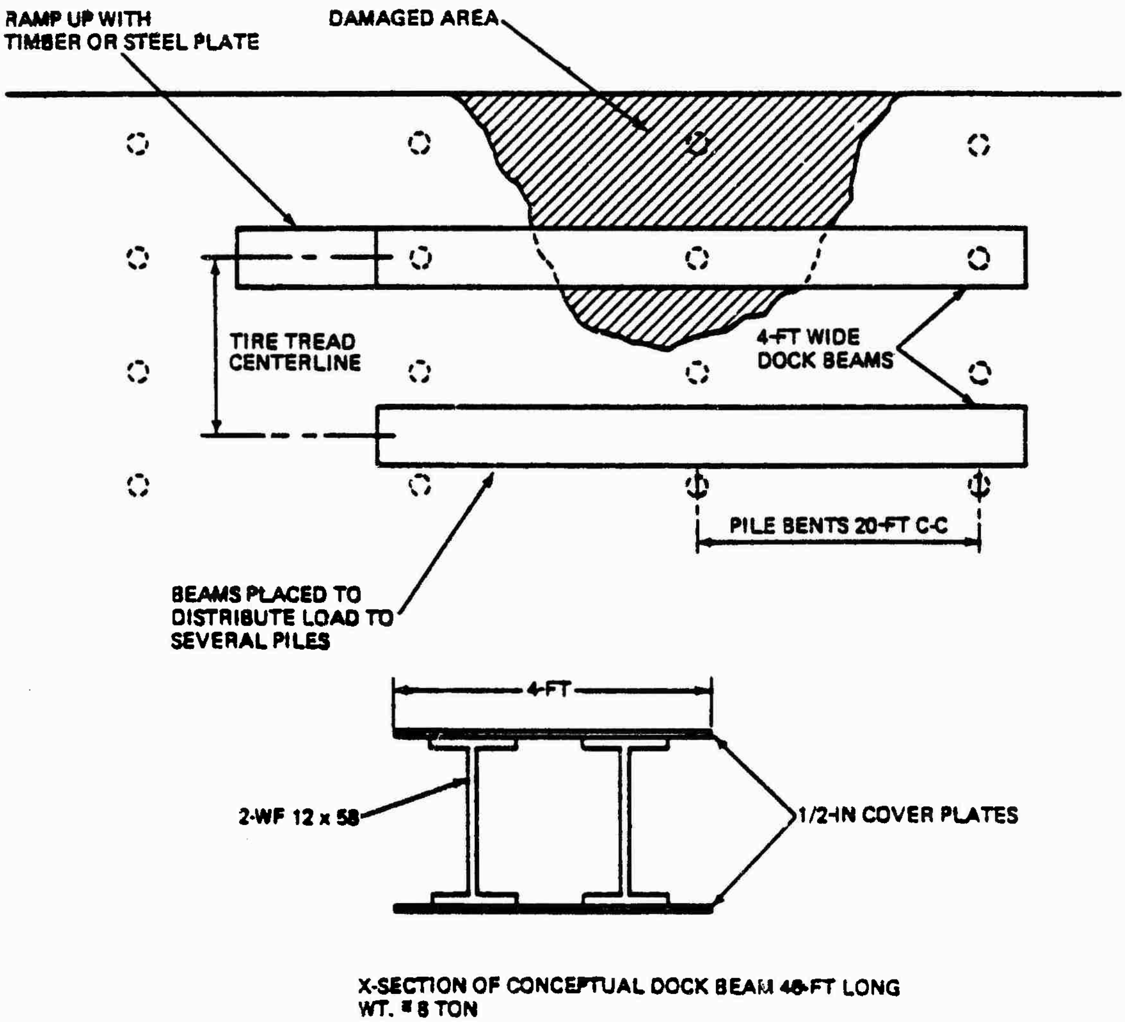


Figure A1. Concept for dock beams to enable crane to traverse damaged portion of quay

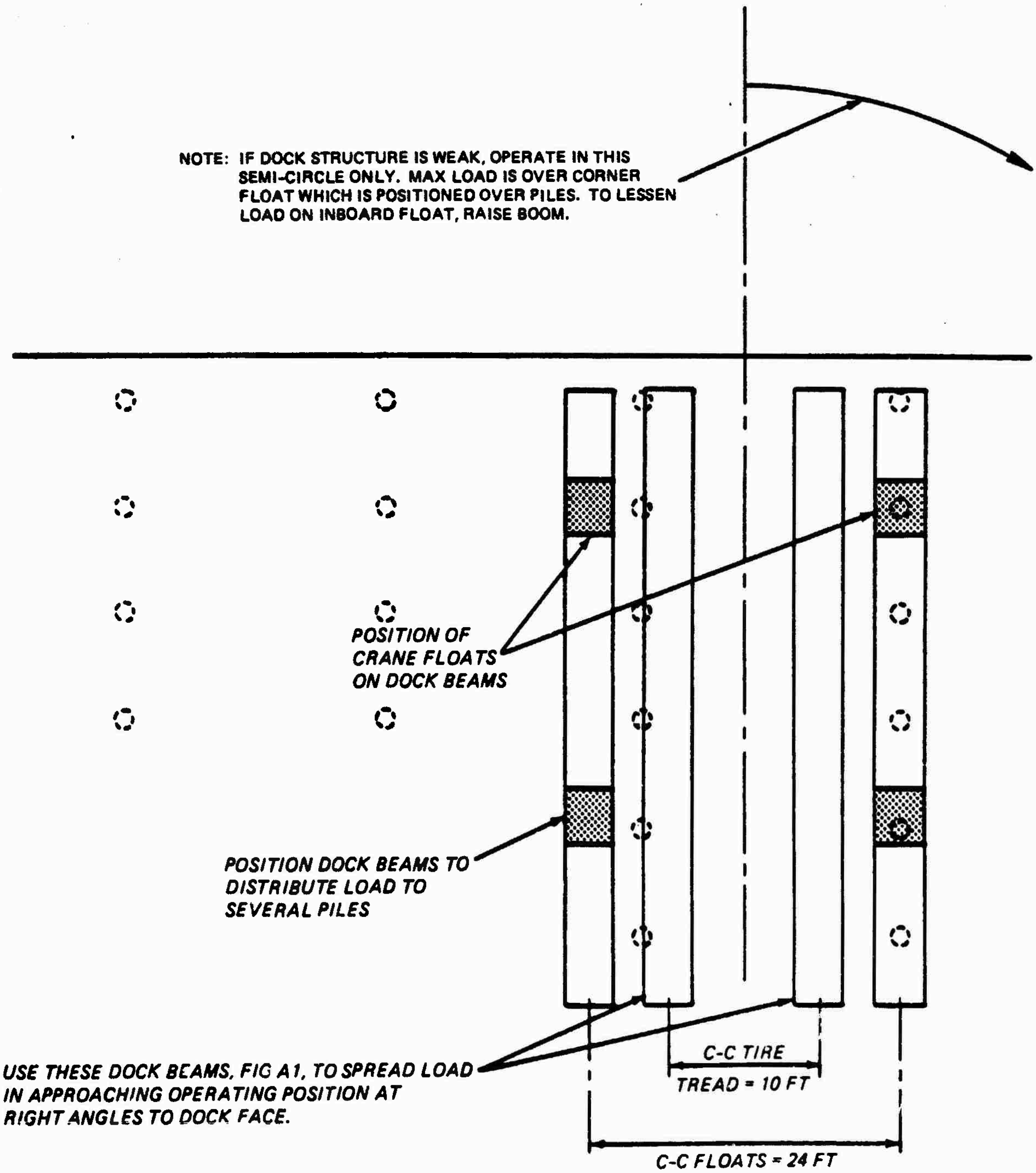


Figure A2. Concept for operating crane using dock beams

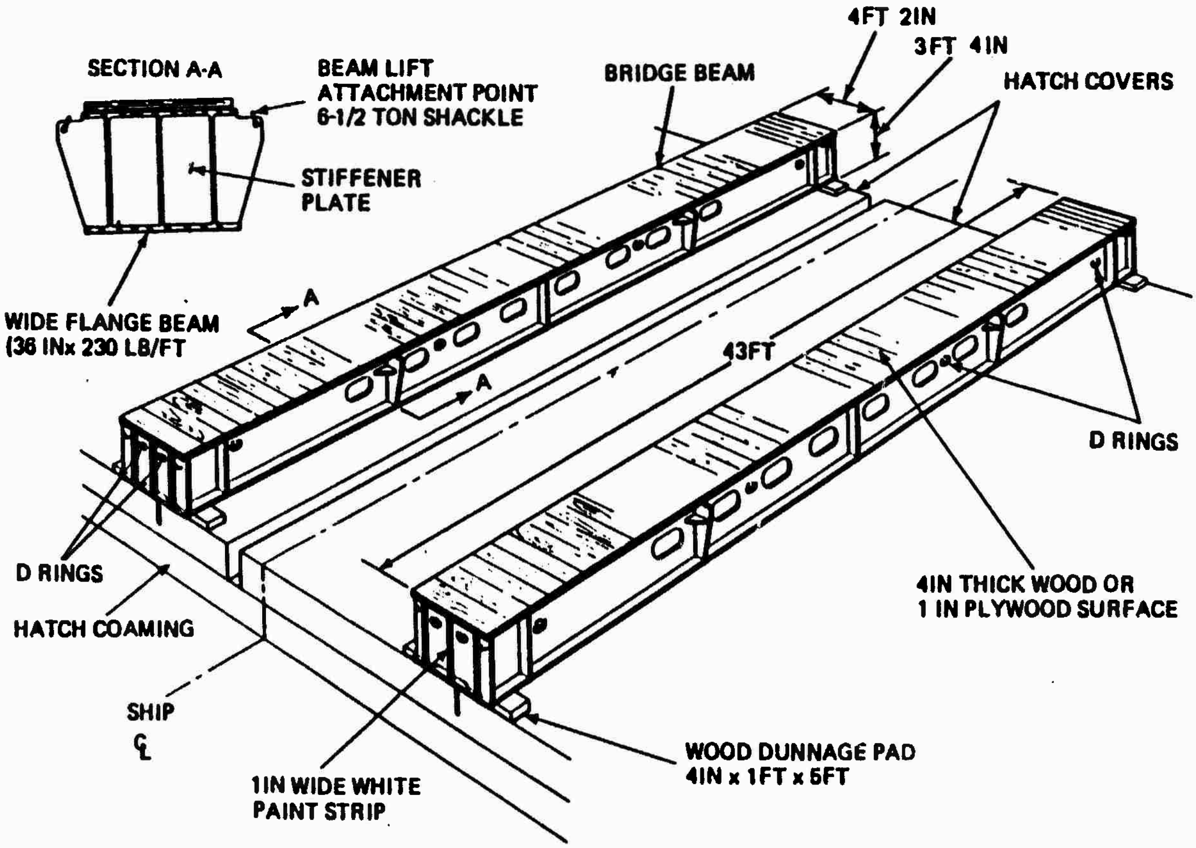
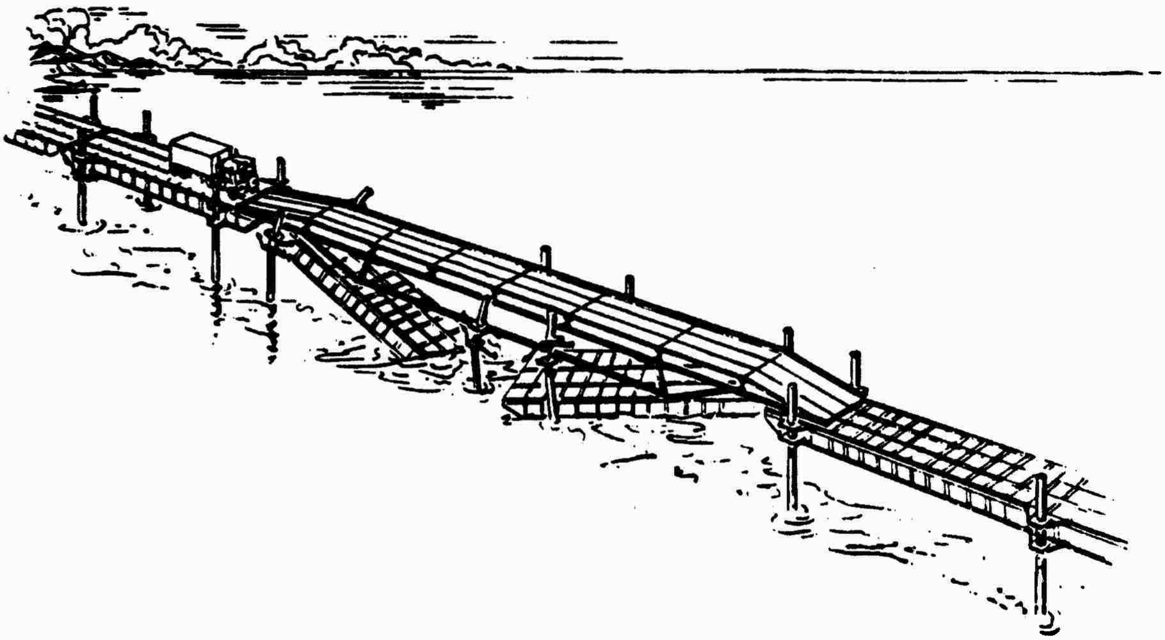


Figure A3. Hatch cover bridging beam



DEPARTMENT OF THE NAVY
NAVAL FACILITIES ENGINEERING COMMAND
200 STOVALL ST., ALEXANDRIA, VA 22332

MAY 1985

Figure A4. Integrated logistic support plan for elevated causeway restore span

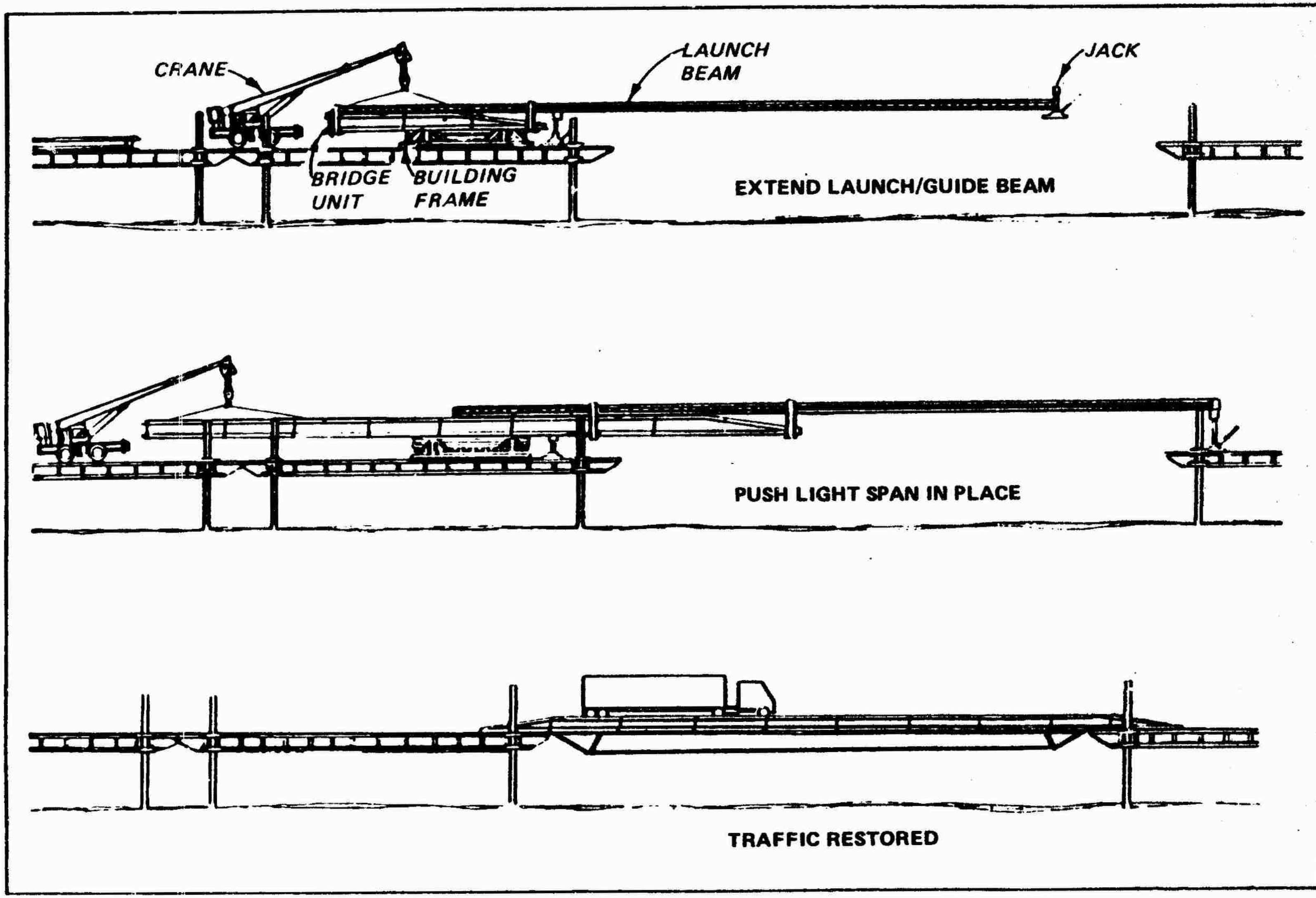


Figure A5. Restore span for a damaged elevated causeway

APPENDIX B

EXPEDIENT PORT REPAIR INNOVATION

SESSION MEETING MINUTES

MINUTES OF INNOVATION SESSION

EXPEDIENT PORT REPAIR

NAVAL CIVIL ENGINEERING LABORATORY

25 June 1985

ATTENDEES: Duane Davis, NAVCIVENGRLAB L53
Cliff Scaalen, NAVCIVENGRLAB L66
Wayne Tausig, Eastport
Ivan Ogburn, Eastport
Farley Shane, Eastport
Jim Osborn, Eastport
John Ferritto, NAVCIVENGRLAB L53
Louis LeDoux, NAVCIVENGRLAB L43
Stan Black, NAVCIVENGRLAB L43
Billy Karr, NAVCIVENGRLAB L53
CAPT (Army) Dan O'Brian, NAVCIVENGRLAB L03B
Charles T. Jahren, NAVCIVENGRLAB L53, Author

During this innovation session the participants were encouraged to advance any idea they had without regard to economic or physical feasibility of any kind. Ideas which did not fit the scenario were also accepted. This document is merely a listing of the ideas. These ideas will be modified, prioritized, and eliminated as necessary in the future.

The ideas fell into the following major categories: Change the off-loading method, use salvaged items, use floatation, use piling, use load attenuating and load transfer devices, use bridging methods, and confine materials. Other general comments were that since this is an expedient situation, factors of safety would not have to be adhered to, and many good ideas may evolve by letting the troops innovate.

Change Container Handling Methods

Under some circumstances it might be easier to change the container handling method than to repair the structure. Tires can be deflated on many pieces of equipment without harm to operations, although the tires may wear

out sooner. Thought could be given to replacing rail mounting devices with tracks or passing containers over damaged areas using cranes or forklifts. Also, traffic could be rerouted past damaged areas using pontoons or transit shed interiors.

IDEAS: Go to a different port.

Go to a different pier.

Use midstream offloading and lighters, helicopters, or float containers.

Pass items over a hole with a forklift or crane.

Modify equipment to reduce load intensity (let air out of tires).

Use causeway ferry.

Bypass damage using barge or pontoons.

Use cables and overhead trolleys.

Use air bearing or air cushions.

Roll containers on hot-dog shaped air bags which act as rollers.

Use Salvaged Items

Since new materials might be in short supply and because transportation might be slow, it would be desirable to use things at hand. Controlled demolition might be used to extricate salvage items from structures. The following is a list of items that might be available near a war-damaged port:

Damaged container cranes (cut members out)

Unused portions of the pier (cannibalize)

Tires

Containers

Corrugated metal roof

Brick

Oil drums

Concrete slabs

Broken concrete

Ship parts (plates, hatch covers, etc.)

Pontoons

Vehicles

Broken bituminous

Railroad rail

Telephone poles

Crane hydraulic systems

Crane cables

Rubble

Floatation

In expedient situations, the buoyant forces of water underneath the pier can be used to support the load. Pontoons could be stacked vertically and used to support the midspan of a deck section. If there is a large tidal variation, the buoyancy chamber can be placed sufficiently deep so it is submerged all the time. Buoyancy chambers could be used for structural support, barges for horizontal transportation, and as a crane platform. It might be possible to float some items into position for erection using floatation devices. Items which float in and jack up might be employed. Some items that might exist around a war-damaged port to provide floatation include:

Barges

Pontoons

Oil drums

Sealed Containers

Timbers

Styrofoam

Piling

Several items might be used for piling in an expedient situation. They might include telephone poles, pipe from chemical plants, railroad rails and sheet piles. One problem with piling is that it might not be possible to drive it through rubble. Pile shoes are available for sheet piling and H piling which help in rubble. If a pipe piling hit got hung up in rubble, it might be possible to grout it into the rubble with tremie concrete or to create a grout bulb by pumping through the piling. If some other type of piling was used (e.g., H pile), it might be possible to insert a tube next to the pile and grout it in.

Jetting might be a possible installation method for piling. The same concept used for the advanced cargo transfer facility might be applied to this problem. This is a spread footing attached to a pipe with water jets in the spread footing. The pile is lowered into the water and jetted as far as possible into the soil.

A crater might be repaired by driving a piling in the middle of the crater and then placing a prefabricated top piece on top of the piling which fits snugly and can be trimmed to the size of the crater.

An expedient column support might be made with an expandable truss that could fit into a container and is similar to those proposed for space station structures. If the column sinks into the soil, some jackup method could be used to maintain the deck height. Water pressure might be used to deploy this item.

Load Transfer and Load Attenuation

It may be possible transfer loads to undamaged piling by various techniques.

If the intensity of a point load causes a problem, it may be possible to spread the load out using airbags, waterbags, or a relieving platform possibly covered with brick pavers. The air- or waterbags could be covered with steel plate or some other material. The bag could conform to surface underneath and provide even load transfer.

It might be wise to transfer the extra load to pilings down at the mudline rather than at the top because there is less buckling length. Cross beams could be placed between undamaged piles to provide a support for new piling.

Bridging

A crater could be bridged using a variety of materials:

Flatbed trailer

Catenary

Balloon support

Shotcrete sprayed on wire

Form concrete patch using corrugated metal roof

Hatch covers from ships

Pontoons

Vehicle frames

Hatch covers

H piles (cover plates at midspan if necessary)

Sheet piling welded together or filled with concrete

Expanding trusses (space shuttle style)

Container bottoms

Whole containers

Confinement

Many items provide very good compressive strength if they are confined even though they are unstable when they are not confined. Possible fill materials:

Foam	Honeycomb
Dirt	Sand
Mud	Rubble
Bricks	Gabions
Bituminous	55 gallon drums
Concrete	Oil
Crushed concrete	Tires
Lime stabilized material	Spheres (strap points on them to improve interlocks)
Water	Containers
Compressed air	Pontoon cubes

Confining devices:

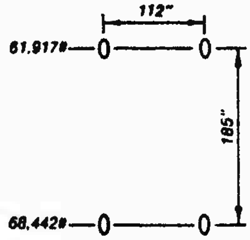
Wire or cable baskets	Pontoon
Fabric	Barge body
Sheet pile	Pressure vessel
Rope net	Van
Plastic bag	Steel or concrete
Sand grid	Culvert sections (stacked vertically and filled with sand or rubble)
Container	

Trade Offs

There may be several practical solutions to an expedient repair problem. The engineer will want to choose the optimal solution. It might be wise to develop a computer program that will assist in making this choice.

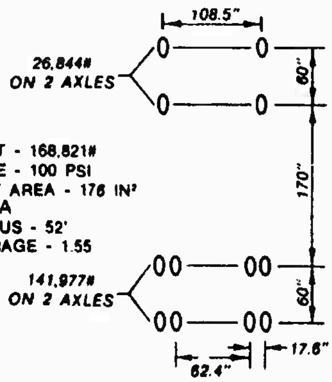
APPENDIX C

VEHICLE LOAD CHARACTERISTICS FOR EXPEDIENT PORT REPAIRS



GROSS WEIGHT - 130,359#
TIRE PRESSURE - 55 PSI
TIRE CONTACT AREA - 688 IN^2
PAYLOAD - NA
TURNING RADIUS - 30'
PASSES/COVERAGE - 1.39

80-TON CRANE

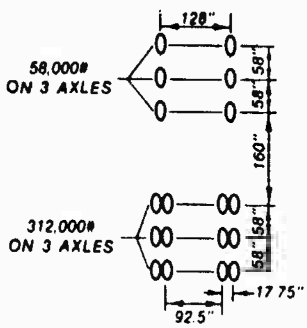


GROSS WEIGHT - 168,821#
TIRE PRESSURE - 100 PSI
TIRE CONTACT AREA - 176 IN^2
PAYLOAD - NA
TURNING RADIUS - 52'
PASSES/COVERAGE - 1.55

140-TON CRANE

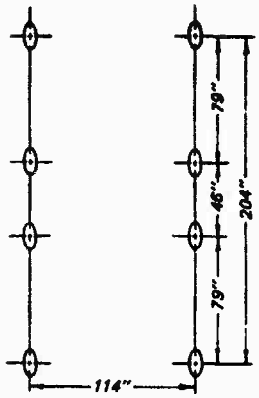
NOTES:

1. GROSS WEIGHT WITH COUNTERWEIGHTS (370,000#)
2. GROSS WEIGHT LESS COUNTERWEIGHT 1 (319,000#)
3. GROSS WEIGHT LESS COUNTERWEIGHTS 1 AND 2 (288,000#)
4. GROSS WEIGHT LESS COUNTERWEIGHTS 1, 2, AND 3 (258,000#)
5. GROSS WEIGHTS DO NOT INCLUDE PAYLOADS



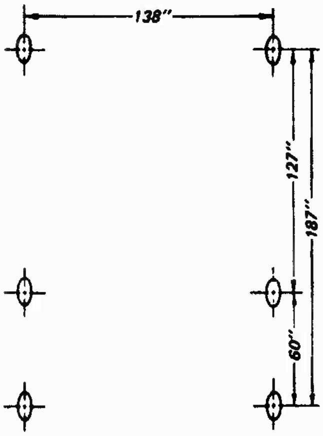
GROSS WEIGHT - 370,000#
TIRE PRESSURE - 100 PSI
TIRE CONTACT AREA - 260 IN^2
PAYLOAD - NA
TURNING RADIUS - 59'
PASSES/COVERAGE - 0.60

250-TON CRANE



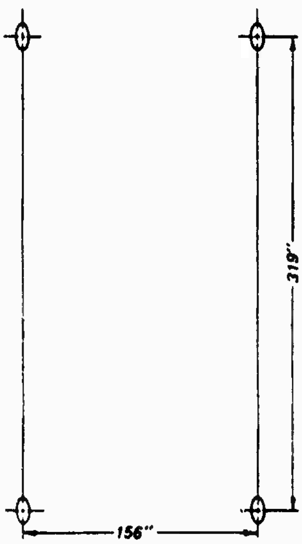
GROSS WEIGHT	=	129,200 LB
SINGLE-WHEEL LOAD	=	16,150 LB
TIRE INFLATION PRESSURE	=	100 PSI
CONTACT AREA	=	154 IN.^{2}
PAYLOAD	=	67,200 LB

SHOREMASTER STRADDLE CARRIER



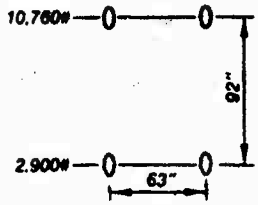
GROSS WEIGHT	=	164,500 LB
SINGLE-WHEEL LOAD	=	27,900 LB
TIRE INFLATION PRESSURE	=	132 PSI
CONTACT AREA	=	210 IN.^{2}
PAYLOAD	=	67,200 LB

CLARK 512 STRADDLE CARRIER



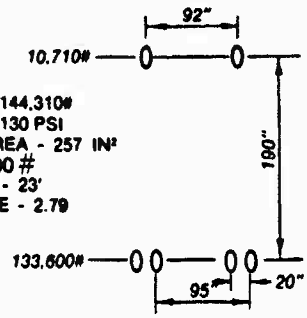
GROSS WEIGHT	=	159,800 LB
SINGLE-WHEEL LOAD	=	43,900 LB
TIRE INFLATION PRESSURE	=	125 PSI
CONTACT AREA	=	380 IN.^{2}
PAYLOAD	=	67,200 LB

BELOTTI B67b STRADDLE CARRIER



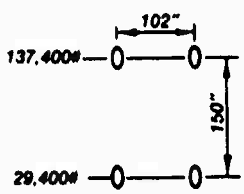
GROSS WEIGHT - 13,660#
TIRE PRESSURE - 45 PSI
TIRE CONTACT AREA - 120 IN²
PAYLOAD - 4,000 #
TURNING RADIUS - 11'
PASSES/COVERAGE - 4.8

4,000-LB FORKLIFT



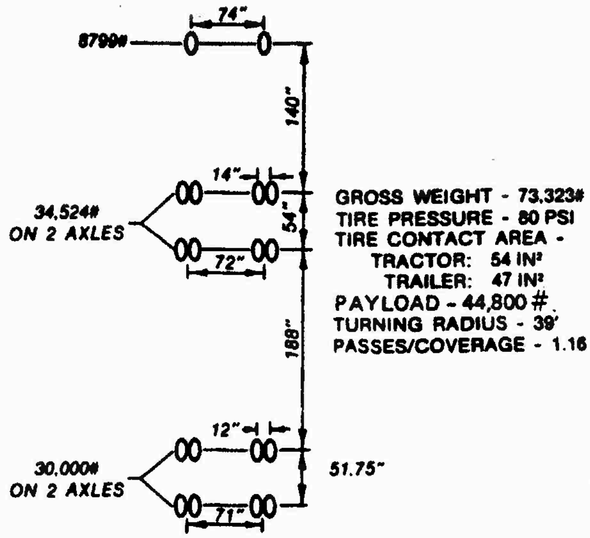
GROSS WEIGHT - 144,310#
TIRE PRESSURE - 130 PSI
TIRE CONTACT AREA - 257 IN²
PAYLOAD - 50,000 #
TURNING RADIUS - 23'
PASSES/COVERAGE - 2.79

HYSTER 620B FORKLIFT

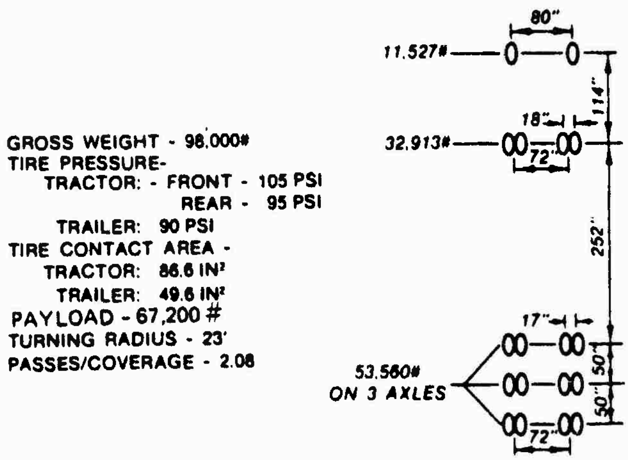


GROSS WEIGHT - 166,800#
TIRE PRESSURE - 92 PSI
TIRE CONTACT AREA - 747 IN²
PAYLOAD - 50,000 #
TURNING RADIUS - 35'
PASSES/COVERAGE - 2.72

CATERPILLAR 988B FORKLIFT

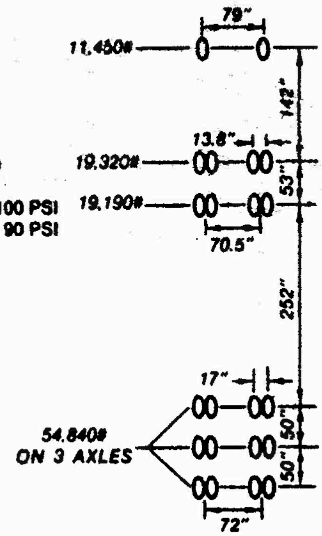


M52 TRACTOR WITH XM871 TRAILER



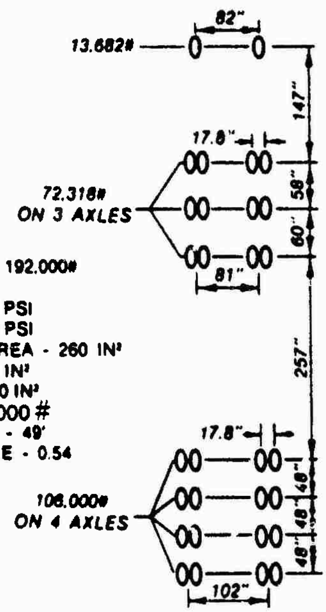
XM878 TRACTOR WITH XM872 TRAILER

GROSS WEIGHT - 104,800#
TIRE PRESSURE-
TRACTOR - FRONT - 100 PSI
REAR - 90 PSI
TRAILER: 90 PSI
TIRE CONTACT AREA--
TRACTOR: 53.5 IN²
TRAILER: 50.8 IN²
PAYLOAD - 67,200 #
TURNING RADIUS - 42'
PASSES/COVERAGE - 0.94



M915 TRACTOR WITH XM872 TRAILER

GROSS WEIGHT - 192,000#
TIRE PRESSURE-
TRACTOR: 85 PSI
TRAILER: 60 PSI
TIRE CONTACT AREA - 260 IN²
TRACTOR: 77 IN²
TRAILER: 110 IN²
PAYLOAD - 120,000 #
TURNING RADIUS - 49'
PASSES/COVERAGE - 0.54



M911 HEAVY EQUIPMENT TRANSPORTER

APPENDIX D

DESIGN AND COMPARISON CALCULATIONS

Table D1. Shear and Moment Demand

	A	B	C	D	E	F	G	H	I	J	K
2	Shear and Moment Demand				HS 20-44	Moment=	80	Shear=	36		
3					Cat 988	Moment=	340	Shear=	158		
4	Span Length =			8.4	P&H 6250	Moment=	360	Shear=	168		
5					Above entries should include 15% impact factor						
6	Load Type				Max Moment		Req'd Sx	in^3	Max Shear	Req'd area in^2	
7					ft. k.	in. k	36 ksi	3 ksi	kips	24 ksi	100 psi
8	------------------------				------	-----	------	-----	----	------	-------
9	1000 lb/sf Uniform Load										
10	1.00' wide				8.82	105.84	2.94	35.28	4.20	0.18	42.00
11	2.00' wide				17.64	211.68	5.88	70.56	8.40	0.35	84.00
12	3.00' wide				26.46	317.52	8.82	105.84	12.60	0.53	126.00
13	4.00' wide				35.28	423.36	11.76	141.12	16.80	0.70	168.00
14	5.00' wide				44.10	529.20	14.70	176.40	21.00	0.88	210.00
15	6.00' wide				52.92	635.04	17.64	211.68	25.20	1.05	252.00
16	8.00' wide				70.56	846.72	23.52	282.24	33.60	1.40	336.00
17	10.00' wide				88.20	1058.40	29.40	352.80	42.00	1.75	420.00
18	12.00' wide				105.84	1270.08	35.28	423.36	50.40	2.10	504.00
19											
20					15% impact factor included below this line.						
21	AASHTO TRUCK										
22	Axel load, 32k				77.28	927.36	25.76	309.12	36.80	1.53	368.00
23	Wheel load, 16k				38.64	463.68	12.88	154.56	18.40	0.77	184.00
24	Half wheel load, 8k				19.32	231.84	6.44	77.28	9.20	0.38	92.00
25											
26	HS 20- 44										
27	Full lane				80.00	960.00	26.67	320.00	36.00	1.50	360.00
28	Half lane				40.00	480.00	13.33	160.00	18.00	0.75	180.00
29	Quarter lane				20.00	240.00	6.67	80.00	9.00	0.38	90.00
30											
31											
32	CAT 988										
33	Axel load (137.2 k)				331.38	3976.56	110.46	1325.52	158.00	6.58	1580.00
34	Wheel load				165.69	1988.28	55.23	662.76	79.00	3.29	790.00
35	Half wheel load				82.85	994.14	27.62	331.38	39.50	1.65	395.00
36	Full lane load				340.00	4080.00	113.33	1360.00	158.00	6.58	1580.00
37	Half lane load				170.00	2040.00	56.67	680.00	79.00	3.29	790.00
38	Quarter lane load				85.00	1020.00	28.33	340.00	39.50	1.65	395.00
39											
40	P&H 6250- TC										
41	Full lane load				360.00	4320.00	120.00	1440.00	168.00	7.00	1680.00
42	Half lane load				180.00	2160.00	60.00	720.00	84.00	3.50	840.00
43	Quarter lane load				90.00	1080.00	30.00	360.00	42.00	1.75	420.00

(Continued)

(Sheet 1 of 5)

Table D1. (Continued)

Shear and Moment Demand

Span Length = 13

HS 20-44	Moment= 120	Shear=	36
Cat 988	Moment= 510	Shear=	160
P&H 6250	Moment= 560	Shear=	224

Above entries should include 15% impact factor

Load Type	Max Moment ft. k.	in. k	Req'd Sx 36 ksi	in^3 3 ksi	Max Shear kips	Req'd area 24 ksi	in^2 100 psi
1000 lb/sf Uniform Load							
1.00' wide	21.13	253.50	7.04	84.50	6.50	0.27	65.00
2.00' wide	42.25	507.00	14.08	169.00	13.00	0.54	130.00
3.00' wide	63.38	760.50	21.13	253.50	19.50	0.81	195.00
4.00' wide	84.50	1014.00	28.17	338.00	26.00	1.08	260.00
5.00' wide	105.63	1267.50	35.21	422.50	32.50	1.35	325.00
6.00' wide	126.75	1521.00	42.25	507.00	39.00	1.63	390.00
8.00' wide	169.00	2028.00	56.33	676.00	52.00	2.17	520.00
10.00' wide	211.25	2535.00	70.42	845.00	65.00	2.71	650.00
12.00' wide	253.50	3042.00	84.50	1014.00	78.00	3.25	780.00
15% impact factor included below this line.							
AASHTO TRUCK							
Axel load, 32k	119.60	1435.20	39.87	478.40	36.80	1.53	368.00
Wheel load, 16k	59.80	717.60	19.93	239.20	18.40	0.77	184.00
Half wheel load, 8k	29.90	358.80	9.97	119.60	9.20	0.38	92.00
HS 20- 44							
Full lane	120.00	1440.00	40.00	480.00	36.00	1.50	360.00
Half lane	60.00	720.00	20.00	240.00	18.00	0.75	180.00
Quarter lane	30.00	360.00	10.00	120.00	9.00	0.38	90.00
CAT 988							
Axel load (137.2 k)	512.85	6154.20	170.95	2051.40	158.00	6.58	1580.00
Wheel load	256.43	3077.10	85.48	1025.70	79.00	3.29	790.00
Half wheel load	128.21	1538.55	42.74	512.85	39.50	1.65	395.00
Full lane load	510.00	6120.00	170.00	2040.00	160.00	6.67	1600.00
Half lane load	255.00	3060.00	85.00	1020.00	80.00	3.33	800.00
Quarter lane load	127.50	1530.00	42.50	510.00	40.00	1.67	400.00
P&H 6250- TC							
Full lane load	560.00	6720.00	186.67	2240.00	224.00	9.33	2240.00
Half lane load	280.00	3360.00	93.33	1120.00	112.00	4.67	1120.00
Quarter lane load	140.00	1680.00	46.67	560.00	56.00	2.33	560.00

<------------------ 15% impact factor included --------------->

(Continued)

(Sheet 2 of 5)

Table D1. (Continued)

	A / B / C	D	E	F	G	H	I	J	K
1	A B C	D	E	F	G	H	I	J	K
2	Shear and Moment Demand			HS 20-44 Moment=	260	Shear=	52		
3				Cat 988 Moment=	1030	Shear=	174		
4	Span Length = 26			P&H 6250 Moment=	1800	Shear=	296		
5				Above entries should include 15% impact factor					
6	Load Type		Max Moment		Req'd Sx	in^3	Max Shear	Req'd area in^2	
7			ft. k.	in. k	36 ksi	3 ksi	kips	24 ksi	100 psi
8	----------------------		------	-----	------	-----	----	------	-------
9	1000 lb/sf Uniform Load								
10	1.00' wide		84.50	1014.00	28.17	338.00	13.00	0.54	130.00
11	2.00' wide		169.00	2028.00	56.33	676.00	26.00	1.08	260.00
12	3.00' wide		253.50	3042.00	84.50	1014.00	39.00	1.63	390.00
13	4.00' wide		338.00	4056.00	112.67	1352.00	52.00	2.17	520.00
14	5.00' wide		422.50	5070.00	140.83	1690.00	65.00	2.71	650.00
15	6.00' wide		507.00	6084.00	169.00	2028.00	78.00	3.25	780.00
16	8.00' wide		676.00	8112.00	225.33	2704.00	104.00	4.33	1040.00
17	10.00' wide		845.00	10140.00	281.67	3380.00	130.00	5.42	1300.00
18	12.00' wide		1014.00	12168.00	338.00	4056.00	156.00	6.50	1560.00
19									
20			15% impact factor included below this line.						
21	AASHTO TRUCK								
22	Axel load, 32k		239.20	2870.40	79.73	956.80	36.80	1.53	368.00
23	Wheel load, 16k		119.60	1435.20	39.87	478.40	18.40	0.77	184.00
24	Half wheel load, 8k		59.80	717.60	19.93	239.20	9.20	0.38	92.00
25									
26	HS 20- 44								
27	Full lane		260.00	3120.00	86.67	1040.00	52.00	2.17	520.00
28	Half lane		130.00	1560.00	43.33	520.00	26.00	1.08	260.00
29	Quarter lane		65.00	780.00	21.67	260.00	13.00	0.54	130.00
30									
31									
32	CAT 988								
33	Axel load (137.2 k)		1025.70	12308.40	341.90	4102.80	158.00	6.58	1580.00
34	Wheel load		512.85	6154.20	170.95	2051.40	79.00	3.29	790.00
35	Half wheel load		256.43	3077.10	85.48	1025.70	39.50	1.65	395.00
36	Full lane load		1030.00	12360.00	343.33	4120.00	174.00	7.25	1740.00
37	Half lane load		515.00	6180.00	171.67	2060.00	87.00	3.63	870.00
38	Quarter lane load		257.50	3090.00	85.83	1030.00	43.50	1.81	435.00
39									
40	P&H 6250- TC								
41	Full lane load		1800.00	21600.00	600.00	7200.00	296.00	12.33	2960.00
42	Half lane load		900.00	10800.00	300.00	3600.00	148.00	6.17	1480.00
43	Quarter lane load		450.00	5400.00	150.00	1800.00	74.00	3.08	740.00
44		<----------	----------	15% impact factor included	----------	----------	---------->		

(Continued)

(Sheet 3 of 5)

Table D1. (Continued)

Shear and Moment Demand

Span Length = 24

	Moment=	Shear=
HS 20-44	220	56
Cat 988	950	172
P&H 6250	1600	288

Above entries should include 15% impact factor

Load Type	Max Moment ft. k.	Max Moment in. k	Req'd Sx in^3 36 ksi	Req'd Sx in^3 3 ksi	Max Shear kips	Req'd area in^2 24 ksi	Req'd area in^2 100 psi
1000 lb/sf Uniform Load							
1.00' wide	72.00	864.00	24.00	288.00	12.00	0.50	120.00
2.00' wide	144.00	1728.00	48.00	576.00	24.00	1.00	240.00
3.00' wide	216.00	2592.00	72.00	864.00	36.00	1.50	360.00
4.00' wide	288.00	3456.00	96.00	1152.00	48.00	2.00	480.00
5.00' wide	360.00	4320.00	120.00	1440.00	60.00	2.50	600.00
6.00' wide	432.00	5184.00	144.00	1728.00	72.00	3.00	720.00
8.00' wide	576.00	6912.00	192.00	2304.00	96.00	4.00	960.00
10.00' wide	720.00	8640.00	240.00	2880.00	120.00	5.00	1200.00
12.00' wide	864.00	10368.00	288.00	3456.00	144.00	6.00	1440.00
	15% impact factor included below this line.						
AASHTO TRUCK							
Axel load, 32k	220.80	2649.60	73.60	883.20	36.80	1.53	368.00
Wheel load, 16k	110.40	1324.80	36.80	441.60	18.40	0.77	184.00
Half wheel load, 8k	55.20	662.40	18.40	220.80	9.20	0.38	92.00
HS 20- 44							
Full lane	220.00	2640.00	73.33	880.00	56.00	2.33	560.00
Half lane	110.00	1320.00	36.67	440.00	28.00	1.17	280.00
Quarter lane	55.00	660.00	18.33	220.00	14.00	0.58	140.00
CAT 988							
Axel load (137.2 k)	946.80	11361.60	315.60	3787.20	158.00	6.58	1580.00
Wheel load	473.40	5680.80	157.80	1893.60	79.00	3.29	790.00
Half wheel load	236.70	2840.40	78.90	946.80	39.50	1.65	395.00
Full lane load	950.00	11400.00	316.67	3800.00	172.00	7.17	1720.00
Half lane load	475.00	5700.00	158.33	1900.00	86.00	3.58	860.00
Quarter lane load	237.50	2850.00	79.17	950.00	43.00	1.79	430.00
P&H 6250- TC							
Full lane load	1600.00	19200.00	533.33	6400.00	288.00	12.00	2880.00
Half lane load	800.00	9600.00	266.67	3200.00	144.00	6.00	1440.00
Quarter lane load	400.00	4800.00	133.33	1600.00	72.00	3.00	720.00

<----------------- 15% impact factor included ----------------->

(Continued)

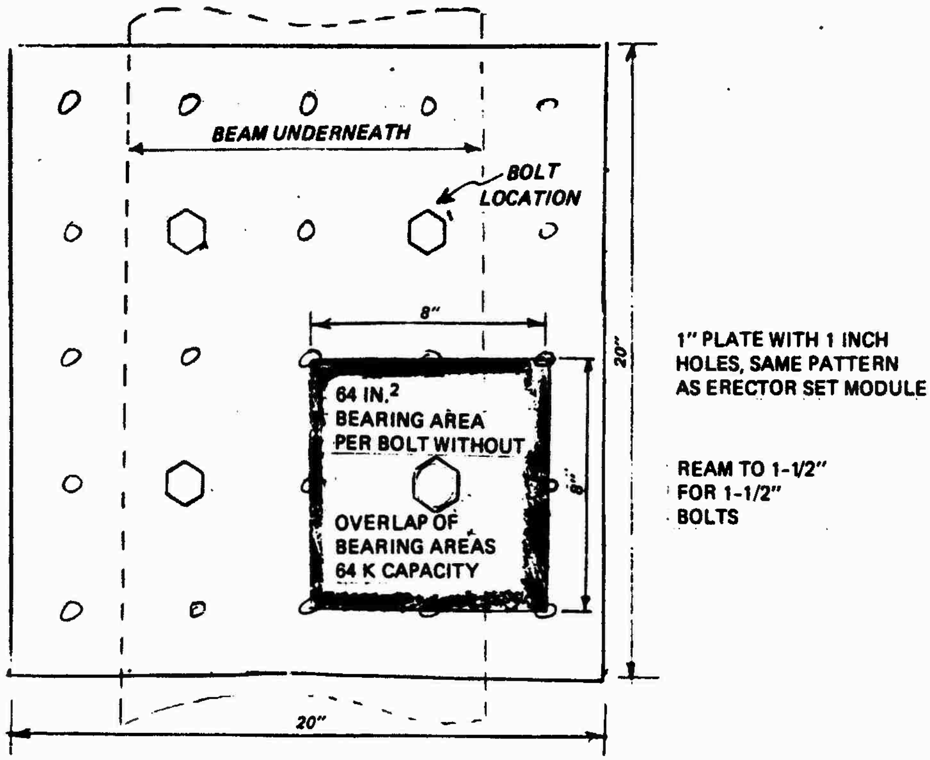
(Sheet 4 of 5)

Table D1. (Concluded)

	A / B / C	D	E	F	G	H	I	J	K
1	A B C	D	E	F	G	H	I	J	K
2	Shear and Moment Demand		HS 20-44	Moment=	530	Shear=	65		
3			Cat 988	Moment=	1750	Shear=	185		
4	Span Length =	40	P&H 6250	Moment=	3000	Shear=	330		
5			Above entries should include 15% impact factor						
6	Load Type		Max Moment		Req'd Sx	in^3	Max Shear	Req'd area in^2	
7			ft. k.	in. k	36 ksi	3 ksi	kips	24 ksi	100 psi
8	------------------------		------	-----	------	-----	----	------	-------
9	1000 lb/sf Uniform Load								
10	1.00' wide		200.00	2400.00	66.67	800.00	20.00	0.83	200.00
11	2.00' wide		400.00	4800.00	133.33	1600.00	40.00	1.67	400.00
12	3.00' wide		600.00	7200.00	200.00	2400.00	60.00	2.50	600.00
13	4.00' wide		800.00	9600.00	266.67	3200.00	80.00	3.33	800.00
14	5.00' wide		1000.00	12000.00	333.33	4000.00	100.00	4.17	1000.00
15	6.00' wide		1200.00	14400.00	400.00	4800.00	120.00	5.00	1200.00
16	8.00' wide		1600.00	19200.00	533.33	6400.00	160.00	6.67	1600.00
17	10.00' wide		2000.00	24000.00	666.67	8000.00	200.00	8.33	2000.00
18	12.00' wide		2400.00	28800.00	800.00	9600.00	240.00	10.00	2400.00
19									
20			15% impact factor included below this line.						
21	AASHTO TRUCK								
22	Axel load, 32k		368.00	4416.00	122.67	1472.00	36.80	1.53	368.00
23	Wheel load, 16k		184.00	2208.00	61.33	736.00	18.40	0.77	184.00
24	Half wheel load, 8k		92.00	1104.00	30.67	368.00	9.20	0.38	92.00
25									
26	HS 20- 44								
27	Full lane		530.00	6360.00	176.67	2120.00	65.00	2.71	650.00
28	Half lane		265.00	3180.00	88.33	1060.00	32.50	1.35	325.00
29	Quarter lane		132.50	1590.00	44.17	530.00	16.25	0.68	162.50
30									
31									
32	CAT 988								
33	Axel load (137.2 k)		1578.00	18936.00	526.00	6312.00	158.00	6.58	1580.00
34	Wheel load		789.00	9468.00	263.00	3156.00	79.00	3.29	790.00
35	Half wheel load		394.50	4734.00	131.50	1578.00	39.50	1.65	395.00
36	Full lane load		1750.00	21000.00	583.33	7000.00	185.00	7.71	1850.00
37	Half lane load		875.00	10500.00	291.67	3500.00	92.50	3.85	925.00
38	Quarter lane load		437.50	5250.00	145.83	1750.00	46.25	1.93	462.50
39									
40	P&H 6250- TC								
41	Full lane load		3000.00	36000.00	1000.00	12000.00	330.00	13.75	3300.00
42	Half lane load		1500.00	18000.00	500.00	6000.00	165.00	6.88	1650.00
43	Quarter lane load		750.00	9000.00	250.00	3000.00	82.50	3.44	825.00
44			<----------------- 15% impact factor included ---------------->						

(Sheet 5 of 5)

Bearing Plate Design Calculations



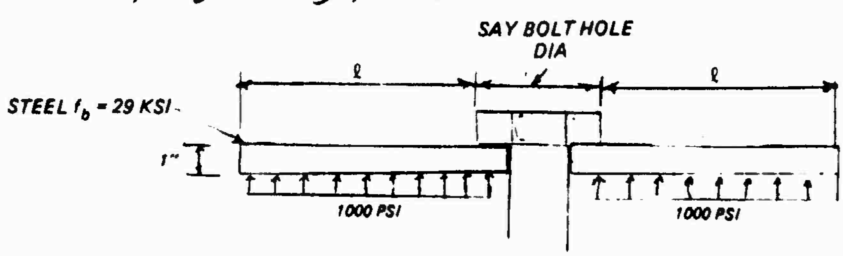
For A 325 1" bolts, Allowable tensile force = 31.42k
Steel manual

allowable masonry bearing, for expedient repair purposes assume $f'c$ = 3000 psi

Steel manual reccommends F_p, bearing pressure, = 0.25 $f'c$ if plate covers all the concrete or 0.375 if the plate covers 1/3 of the support.

assume F_p allowable = 0.33 $f'c$ = 1000 psi

for a 1" strip of bearing plate:



I of a 1" × 1" bar $= \frac{bh^3}{12} = \frac{1}{12}$ in^4

$f = \frac{Mc}{I} \rightarrow M = \frac{If}{c} = \frac{29}{(12)(0.5)} = 4$ kip-inches

$M = \frac{w\ell^2}{2} \Rightarrow \ell = \sqrt{\frac{2M}{w}} = \sqrt{\frac{2(4)}{1}} = 2.82"$ say 3" ok for ℓ

(Continued)

Assume a 1" plate can spread load over a 7" x 7" square resulting in 1000 psi bearing pressure on concrete.

2ℓ + bolt hole dia.

Bearing plate is good for 49, Kip / bolt

OK because 1" bolt, max tensile strength is 31.42 k

Try 1½" bolt for high stress connections

Allowable tensile force 70.68 Kips

try 1½" plate

$I = \frac{bh^3}{12} = \frac{1.5^3}{12} = 0.28 \text{ in}^4, \quad M_{max} = \frac{If}{c} = \frac{(0.28)(24)}{0.75} = 8.96 \text{ kip-in}$

$\ell = \sqrt{\frac{2 M_{max}}{w}} = \sqrt{2(8.96)} = 4.23$ say $4.25"$

Assume plate can spread load over a 11 x 11 square

2ℓ + bolt dia

121 □" → 121, K > 70.68, OK

try 2 - 1" plates, $M_{max} = 2 \times 4$ kip inches $= 8$ kip-inches

capacity for a 1" plate

$\ell = \sqrt{2(8)} = 4'$ ⇒ 10 x 10 square ⇒ 100 kips, OK

better to stack 2 - 1" plates to eliminate the need for another plate size.

Steel Plate Concept

Structural Demand

Only moment is considered. Shear and end reaction should not be controlling factors due to the nature of the repair.

		Case 1	Case 2	Case 3	Long Span Example
Max moment demand 1000 PSF, 8' wide	ft-k	70.56	169.0	676.0	1600
HS-20-44					
Longitudinal, full	ft-k	N/C	120	260	530
transverse, full	"	N C	60	180	310
wheel load	"	38.	N/C	N/C	N/C
Cat 988 wheel load	ft-k	165.69	N/C	N/C	N/C
P&H 6250-TC					
Longitudinal, full	ft-k	N/C	580	1040	3000
Transverse, full	"	N/C	580	1040	N/C

N/C = not critical, by inspection

Structural Design

Moment requirement

		Case 1	Case 2	Case 3	Long Span Example
HS 20-44/1000 psf	ft-k	70.56	169.0	676.0	1600
CHV	ft-k	165.69	580	1040	3000

Plate Selection

	Case 1	Case 2	Case 3	Long Span Example
HS 22-44 /1000psf	1" 100 ksi 1" 60 ksi 1½" 36 ksi	1½" 100ksi 1½" 60 ksi N/A 36 ksi	N/A	N/A
CHV loading	1" 100 ksi 1½" 60 ksi 2" 36 ksi	2" 100 ksi ?? close assume OK	N/A	N/A

Use 100 ksi 1" plate for all Case 1 repairs
Use 100 ksi 2" plate for all Case 2 repair

for selection All repairs: 1 PL-8X10X1" 100 KSI; 2 PL-8X15X2" 100 KSI

use 8X20X2" PL to avoid flame cutting time

(Continued)

(Concluded)

Shipping Weight	Case 1	Case 2	Case 3	Long span, ex.
	4000	25600	N/A	N/A

Total 3 case 1, 6 case 2 } 165,600 lb
say 166,000

Shipping Cubage

Assume plate comes in container compatible racks, dimensions 6" x 8' x 20'. Each rack contains 4-1" plates or 2-2" plates or 1-2" plate and 2-1" plates.

cubage → 10 80 Total 510

Manhours

Flame cut plate	8	N/A	
Place the plates (5 men, 1.5 hr.)	8	16	
Secure the plates	8	16	Total for 3 case 1, 6 case 2
	24	32	264 MH

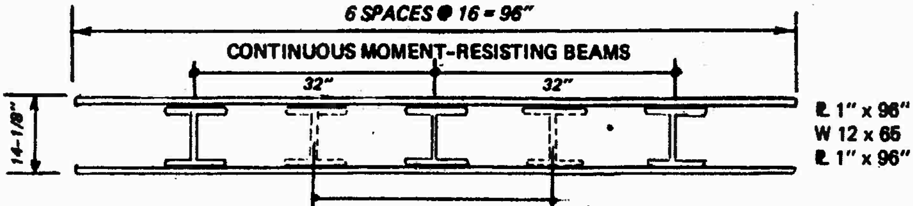
Schedule time

Primarily, crane time controls, some schedule time to secure plates

Place plates	1.5	3.0	Schedule time 3 case 1, 6 case 2
Secure plate	0.5	1.0	
	2.0	4.0	30 ~~MH~~ hrs x 1.2 = 36

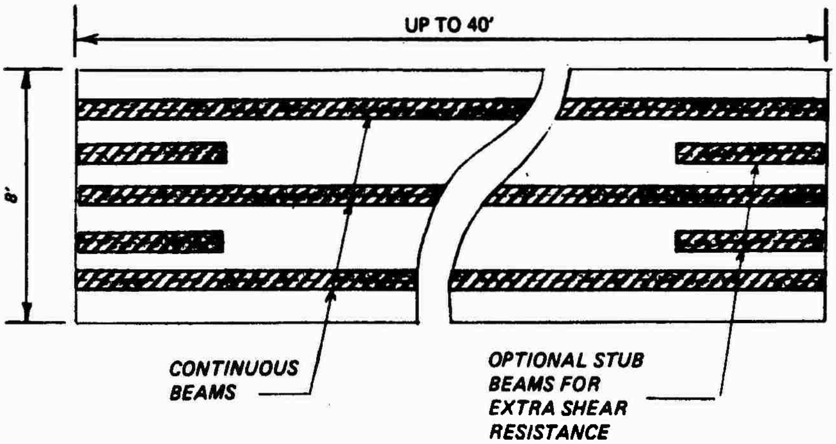
Cost 83,000

Consider two types of modules:



may be added at end spans for extra shear resistance

CROSS SECTION
TYPE A MODULE



PLAN
TYPE A MODULE

Structural Calcs:

Component	$I_{component}$ in^4	Qty	Extension
W12X65	533	3	1599
PL 1"x96"	27	2	54
Parallel axis (PLs)	2400	2	4800

Total I for Module 6453 → $S_x = 2151$

If $f_b = 36$ ksi → Moment resistance for Module = 6453 kip ft

(Continued)

Check available shear resistance

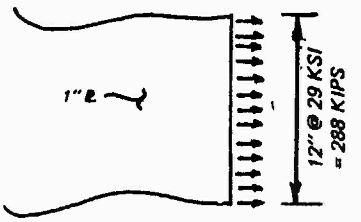
Assume web thickness x depth of beams is effective in resisting shear. $f_v = 24$ ksi

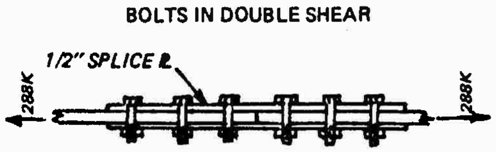
A_w W12X65 = 390 X 12.12 = 4.72 = 113 kips/beam

with 3 beams, Max shear = 340 kips
with 5 beams, Max shear = 567 kips

<u>Splices</u>

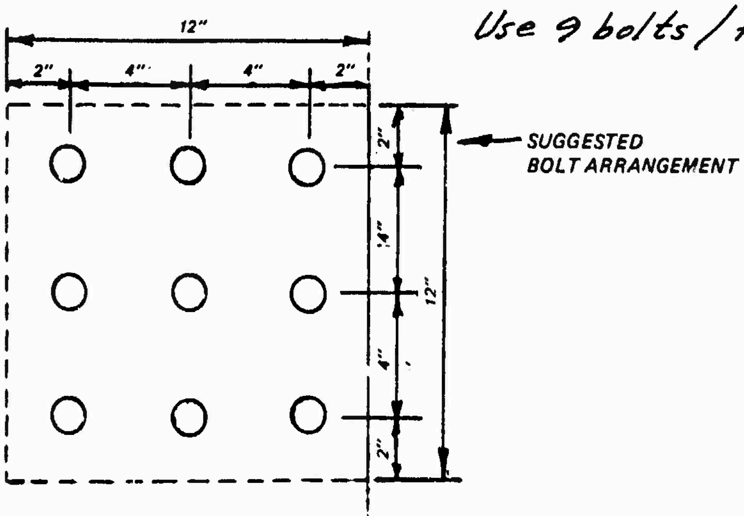
Develop full strength of 1" plate. Assume stress in plate = 24 ksi and select bolts per AISC criteria. Repairs will actually be used at f_b = 36 ksi, Assume overstress on bolts will be the same as overstress on plates for conceptual design purposes.





Assume A325 bolts
Bearing connection
Threads Excluded
34.56 Kip / Bolt
8.33 bolts req'd

Use 9 bolts / ft



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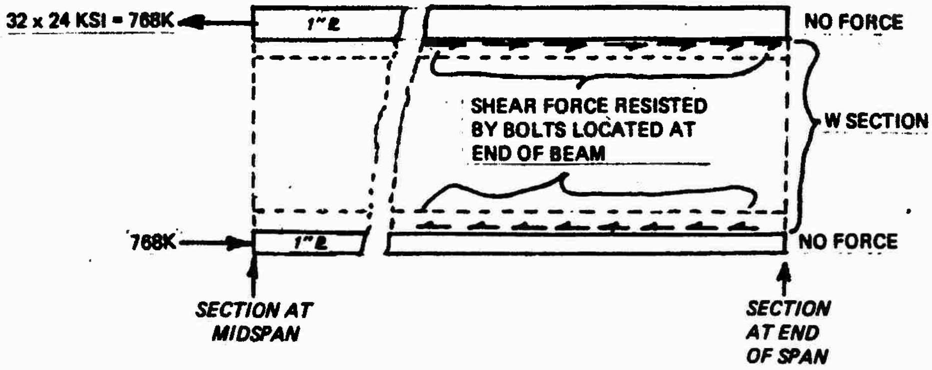
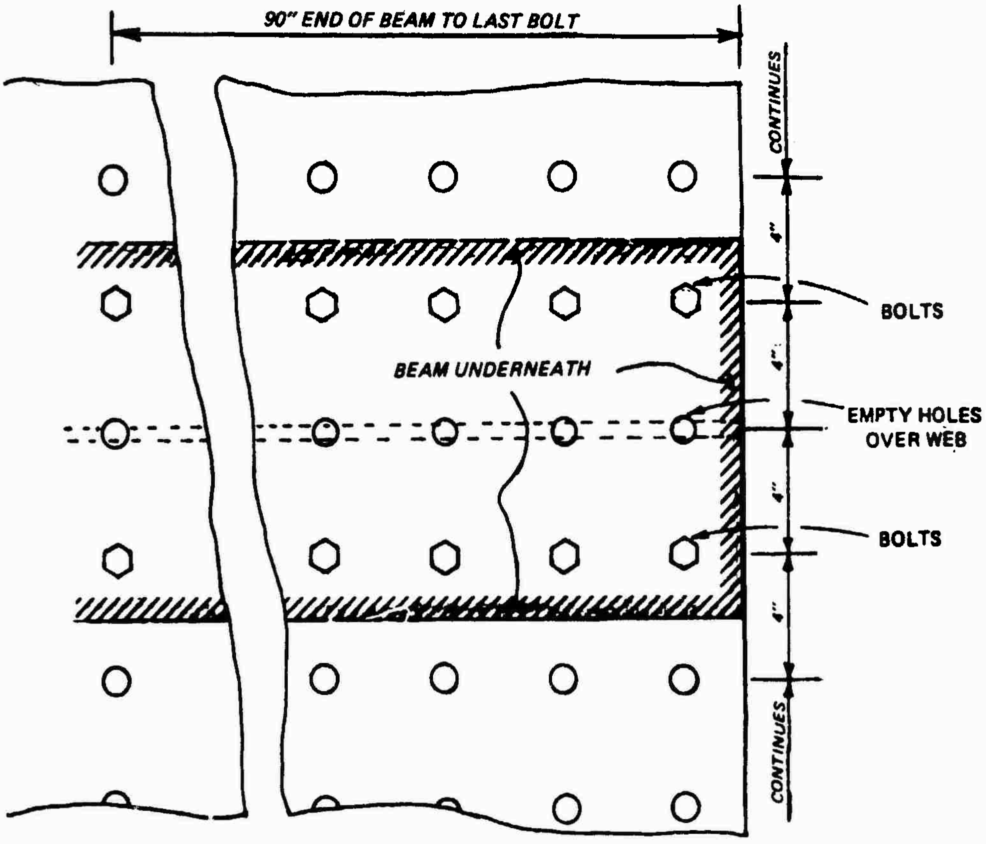
Joint between beam & plate. Develop full strength of plate for 32" width



Assume: A325 1" bolts, bearing conn, threads excluded from connection. 17.28 kips/bolt → 43 bolts required. Use 44 bolts.



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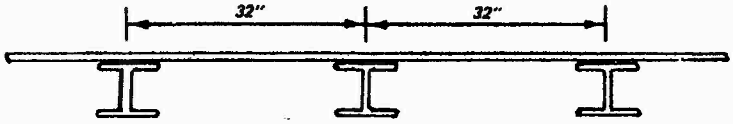


1)
W 12X65 beams

Component	Bottom to centroid	Area	I	Parallel axis	Total I
W 12X65	6"	57.3	1599	4.07	2548
1" ℄	12.5	96	27	2.43	593
		153.3			Total I for Module = 3141

Neutral axis 10.07" from bottom.

Sx = 311

Mmax f_b = 36 ksi = 935

②

W 12X99 beams	6.4"	87.3	2577	3.6	3708
1" ℄	13.3"	96.0	27	3.3	1072

N/A @ 10.01 Total I for Module = 4780

Sx = 478

Mmax f_b = 36 ksi = 1434

③

W 12 X 190	7.2"	167.7	5670	2.8"	6985
1" ℄	14.9"	96.	27	4.9"	2331

Atotal 263.7 9317
NA = 10"

Sx 931

f_b = 36 KSI Mmax = 2795 ftk

(Continued)

Comparison	Type B ①	②	③	Type A
Beams	W12X65	W12X99	W12X190	W12X65
Moment resistance per module, fb=36ksi, ft-kip	935	1435	2800	6450
Shear resistance per module	340 k	534k	1097k	340'k
Weight				
module only				
20', lb	10,300	12,340	17,800	16,700
40', lb	20,600	24,680	35,600	33,400
w splice pls, transverse stiffeners, etc. 3000 lb for 20' TYPE B, 6000 lb for 40' TYPE B, 5,400 for Type A 20', 10,800 for Type A 40'				
20'	13,300	15,340	20,800	22,100
40'	26,600	30,680	41,600	44,200
Shipping Cubage				
Use 8' X 40' X 16" racks				
No. of beams in a rack	15	10	8 Rack splits in half for lifting	15
Beams				
20' module	43	64	80	43
40' module	85	128	160	85
Plates				
20' module	20	20	20	40
40' module	40	40	40	80
Misc.				
20' module	20	20	20	40
40' module	40	40	40	80
Total				
20' module	83	104	120	123
40' module	165	208	240	245
Prefab 20'	212.8	assume 16" high rack		
40'	425.6			

(Continued)

Man hours

		Type B 20'	Type B 40'	Type A 20'	Type A 40'
Bolting					
Beam to ℄ conn.	Ea	264	264	528	528
Splices	Ea	360	720	720	1440
Total	Ea	624	984	1248	2000
M.H. for bolting 10 bolt/MH	M.hr.	63	100	125	200
M.H. to lift & Move 1.5 crew hous to move with crane 5 man crew					
Moves Required		2	2	2	6
	M.H.	15	15	15	45
Secure and Provide Ramps	M.hr.	40	40	40	40
Total		118	155	180	285

Schedule Time

		Type B 20'	Type B 40'	Type A 20'	Type A 40'
Bolting, ten man crew 10hr a day	hr.	14	18	23	33
Lifting, 1.5hr/Lift	hr.	3	3	3	9
Securing, Ramps	hr.	1	1	1	1
Total	hr.	10	13	16	30
Schedule time hr. x1.2		12	16	19	36

(Continued)

Selection

	Case 1	Case 2	Case 3	40' span
HS 20-44, 1000 psf				
Critical Load, Moment	HS20-44 full	1000psf 8'	1000psf 8'	1000psf 8'
Max Moment	80	169	676	1600
Critical load, Shear	HS20-44 full	1000psf 8'	1000psf 8'	1000psf 8'
Max Shear	36	52	104	160
Select →	TYPE B1 10'x16'	Type B1 20'x16'	Type B1 30'x29'	Type B3 40'x16'
Schedule hours	18	24	42	72
total for berth 240 hr				
Man hours total for berth ← 2365 Mhr.	180	236	409	570
Shipping weight.	13,300	26,600	59,850	88,400
total 259,350 say 260,000				
Shipping cubage total	83	165	372	240

Aquisition cost $1.00/lb

Shipping Prefabed.

	Case 1	Case 2	Case 3	40' span
Cubage total 4143	212.8	425.6	957.6	851.2
Erector Set				
Prefab Sch hr 3hr/unit Total 63	6	6	9	6
M.H.				
Lift	30	30	45	30
flame cut	16	16	24	
Secure, provide ramps	8	8	12	8
	54	54	81	38
Total 567				

Aquisition cost $0.75/lb

(Continued)

Selection:

		Case 1	Case 2	Case 3	Long Span
Container Handling Vehicles. Critical Moment load		P&H 6250 TC Longitudinal	Same ←	same ←	Same ←
Max Moment		360 ft-k	560 ft-k	1800 ft-k	3000 ft-k
Critical Shear Load		P&H 6250 TC Longitudinal	Same ←	Same ←	Same ←
Max shear		168 k	224 k	296 k	330 kip
Select		Type B1. 10'x16'	Type B1 20'x16'	Type B3 30'x20'	Type A 16'x40'
Schedule hrs. Total 240	hr.	18	24	42	
Man hours Total 2365	h-hr	180	236	409	
Shipping weight Total 293	lb	13,300	26,600	93,600	
shipping cubage Total 1791	cu ft.	83	165	552	

Shipping Prefabed.

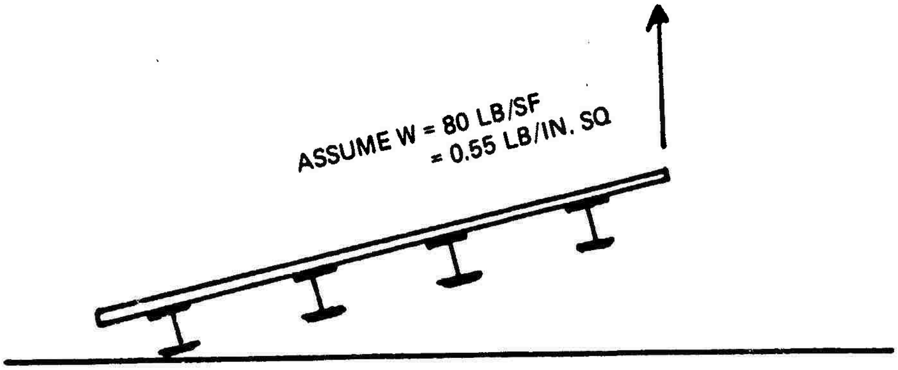
Cubage
Total 4143
Sch hrs.
Total 63
M.H.
Total 567

Weight
293,000 lb

(Continued)

Erector set concept

Can modules be tilted without damage?
The answer is yes



To tip 1-20' section

$$M = \frac{wl^2}{8} = \frac{(20 \times 12 \times 0.55)\,(96")^2}{8 n} = 152{,}064 \text{ in lb}$$

Assume the load is spread over an 8' width of the plate, $S_x = 69 \text{ in}^3$

$$\frac{152{,}069}{52} = 8940 \text{ psi} \quad \text{OK}$$

Erector Set Concept (Reinforced Plate Subconcept)

This is a subconcept to "erector set" concept. Beams are attached to steel plate so the beams will protrude through damaged areas. No splices between modules.

	Case 1	Case 2	Case 3	total for Berth
Material Required				
PL, 1"	2 Pcs 8'x10'	2 Pcs 8'x20'	3 Pcs 8'x30'	
Beams				
L.F req'd	20	20	60	
Selection				
HS 20-44	W12x65	W12x65	W12x65	
CHV	W12x65	W12x65	W12x190	
Bolts	96	96	360	
Shipping Weight				
Plate	6400	12800	28,800	
Beams				
HS-20-44/1000 PSF	1300	1300	23,400	
CHV			68,400	
Total				
HS 20-44	7700	14100	52,200	160,000
CHV			97,200	205,000
Shipping Cubage				
Plate cuft	20	40	90	
Beams HS 20-44	14	14	43	
CHV			80	
Bolts Misc			10	
Total				
HS 20-44	34	54	143	569
CHV			180	606

(Continued)

Manhours	Case 1	Case 2	Case 3	total
Obtain Materials	8	8	12	
Flamecut Pl's & Beams	8	8	24	
Bolt	10	10	36	
Set modules	8	8	12	
Secure modules to deck	8	8	12	
	42	42	96	474
				say 476

Schedule Hours				
Obtain Materials	3	3	5	
Bolt	2	2	3	
Set modules	3	3	5	
Secure modules	2	2	3	
	10	10	16	106
				x1.2
				127

Task: provide pier cap for case 3 damage. One pile may be driven in the middle of the damaged span, if necessary.

Max. span length w/o pile — 20'

Tributary area - 20 x 20 = 400 S.F. ⇒ 400,000 lb

20 k/ft

P&H 6250-TC, heavy wheels @ pier cap.

Say 350 k spread over 10 ft.

35 k/ft for 10 ft

· Moment demand

20' span $\frac{20(20^2)}{8}$ = 1000 ft k 1000 psf load

1080 ft k P&H 6250TC Transverse

10' span $\frac{20(10)^2}{8}$ = 250 ft k 1000 psf load

450 ft k P&H 6250 TC Transverse

Shear/Reaction

20' span	200 k	1000 psf
	272 k	P&H 6250-TC Transverse
10' span	100 k	1000 psf
	188 k	P&H 6250-TC Transverse

So P&H 6250 TC is usually the critical load.

(Continued)

Expedient pile Cap.

Material selection

		HS 20-44/ 1000 psf load		CHV	
		10' span	20' span	10' span	20' span
Moment demand ft k		250	1000	450	1080
Req'd Sx		83.3	333	150	360
Assume 20' or 30' lengths →		2-W12x65 Sx = 176	2-W12x133 Sx = 366	2-W12x65 Sx = 176	2-W12x133 Sx = 366
W12X190 Beam is required for "erect & set" concept Type B-3. and steel beam concept			Use W12X190 or 2-W12x65 w/ 1"x36" PL top & Bottom		Use W12X190 or 2-W12x65 w/ 1"x36" PL top & Bottom
Weight					
Beams:	W12X65 lb	1300		1950	
	W12X190 lb		3762		5700
	W12x65 & PL 3'x20'x1" lb		2871		4350
Extra reinforcing near pile, if necessary.	lb	1000	1000	1000	1000
Shipping Cubage	cu.ft.	40	50	40	50
Man hours					
Gather Materials		8	8	8	8
Attach Beams		6	8	8	10
Bolt plates, if used 640 bolts		N/A	32	N/A	64
Pile Attachment, if used		8	8	8	8
		22	56	24	90
Schedule hours					
Gather materials		1.5	1.5	1.5	1.5
Attach beams		4	4	4	4
Bolt PL's			8		12
Total		5.5	13.5	5.5	17.5
x1.2		7	16	7	20
Pile Attachment		4	4	4	4

(Continued)

Expedient Pile Cap

Summary

		10' Gap		20' Gap	
		HS 20-44 1000 psf	CHV	HS 20-44 1000 psf	CHV
Shipping weight	lb	1300	3000-4000	2000	4000-6000
Shipping Cubage		← 40 →		← 50 →	
Man hours					
Beams only		← 25 →			
Beam w/ PL's Bolted on			55		90
add for pile attachment		← 8 →			
Schedule hours					
Beams only		← 7 →			
Beams w/ PL's bolted on			16		20
add for pile attachment		← 4 →			

Steel Beam Mat Concept

Assume one wheel load or repair area for most vehicles

8.4 dia circular crater

	Req'd Sx	Req'd Shear Area
HS 20-44 - ½ wheel load	6.44	0.38 ←
1000 lb/SF - one ft wide	2.94	0.18

Select 2-W 6X15.5 per foot of width.
(smallest W6 with 6" flange width)

S_x = 2 X 10 = 20 > 6.44, ok
Shear area = 2 X 6 X 0.235 = 2.82 > 0.38 ok
depth web thickness

For a 10 X 10 repair:
Shipping weight 2 X 10 X 10 X 15.5 = 3100 lb

shipping cubage (one next to the other stacked 2 high in a one foot rack.): 50 cu ft

Schedule Time: ¼ hour per beam x 20 beams → 5 hours.

PAH 6250 TC Use quarter lane load Req'd S_x = 30 Req'd Shear Area 1.75 in²

Select W 12X53 (smallest W12 w̄ 10" flange)
S_x = 70.7 > 30 OK Shear area = 4.16 in² > 1.75 OK

For a 10'X 10' repair
Weight = 4800 lb
cubage = 56 cu ft
Schedule Time = 6 hr.

(Continued)

Beam Concept:
13 foot gap

		Reqd S_x (in^3)	Reqd Shear Area (in^2)
HS 20-44 - 1/4 lane load		10.00	0.38
HS 20-44 - 1/2 transverse	37.37 ftk	12.45	0.58 ←
1000 lb/sf, 1 ft wide		7.04	0.27
6250-TC 1/4 lane		46.67	2.33 ←
Cat 988 - 1/2 transverse	130 ftk	43.33	2.29

For HS 20-44 transverse loading.

select W6 x 15.5, 2 per 2' width

$S_x = 2 \times 10 = 20 > 12.45$ OK

Shear Area $= 2 \times 6 \times 0.235 = 2.82 > 0.58$ OK

For A 10 X 20 mat (cut 40' beam in half)

Weight = 6200 lb

Shipping cubage = 100 cubic feet

Schedule Time 1/4 hour/beam = 5 hours

For 6250-TC 1/4 lane select - W 12 x 53

$S_x = 70 > 46.67$ OK

Shear area $= 4.16\ in^2 > 2.33$ OK

For a 12 x 20 mat (cut 40' beam in half)

Shipping cubage = 192 cu ft (side by side)

Weight = 12,720 lb

Time 1/2 hour/beam = 6 hours

(Continued)

Beam Concept
24 foot gap.

	in^3 Req'd S_x	in^2 Req'd Shear Area
HS 20-44 1/4 lane load	18.33	0.58
H.S. 20-44 1/2 transverse load 8 kip	26.66	0.65 ←
1000 lb/sf 1 ft wide	24.00	0.50
P&H 6250-TC 1/4 lane	133.33	3.00 ←
Cat 988 1/2 Transverse 325 kip	108.33	2.66

For H.S 20-44 transverse 1/2 load

select W 12 X 53 S_x = 70.7 > 26.66 OK
shear area = 4.16 > 0.58 OK

For a 10 X 30 repair:
Shipping Weight = 15,900 lb
Cubage = 240 cu ft
Schedule Time = 5 hours

For P&H 6250-TC 1/4 lane

select W 12 X 99 SX = 135 > 133.33 OK
shear area = 12.75 X 0.582 = 7.42 > 1.290

for a 30' X 12' repair.

Weight = 35,640
Cubage = 288 cu ft
schedule time = 6 hours

(Continued)

Beam Concept
40' gap.

		in^3 Reqd S_x	in^2 Reqd shear area
HS 20-44	1/4 lane load	49.17	0.68
HS 20-44	1/2 Transverse 155	51.66	0.67
1000 lb/SF, 1 ft wide		66.7	0.83 ←
P&H 6250 TC	1/4 lane	250	3.44 ←
Cat 588	1/2 transverse 640 Ht	213	2.8

For H.S. 20-40 & 1000 lb/SF only

Select W 12×53 $S_x = 70.7 > 66.67$ OK
Shear area $= 14.16\ in^2 > 0.68$ OK

For a 10×40 repair

Shipping Cubage	400 cu ft
Weight	21,200 lb
Time 45 min/Beam	8 hours

For 6250-TC select W 12×190 $S_x = 263 > 250$ OK
Shear Area $\approx 14\ in^2 \pm > 3.44$ OK

For a 12×40 repair

Shipping cubage	
Side by side 4'×16"×40' racks.	638.4 cu ft
Weight	91,200 lb
Schedule time	10 hours

(Continued)

Beam Concept

Flame cut beams

6"	3/ hr	0.33 MH
12" Light	2/ hr	0.5 MH
12" heavy	1/hr	1 MH

Bolt cross braces 40 Bolts / 100 sq ft 8 MH

Build ramps (wood)
cut 10 12"x12" 10' long diagonally w
with chain saw 1 MH Each = 10 MH
Place 0.25 MH each x 20 5 MH
secure against movement 5 MH
20 MH

10 x 10 Mat, 6" Beams
Flame cut 20, 6" Beams 20 x 0.33 MH = 7 MH
Place 20 6" Beams 5 man crew x 20 x 0.25 = 25 MH
Bolt 100 sq ft 8 MH
Build ramps 20 MH
60 MH

10 x 20 Mat 6" Beams
Flame cut 20 - 6" Beams 20 x 0.33 MH = 7 MH
Place 20 6" Beams 5 men x 20 x 0.25 = 25 MH
Bolt 200 SF = 16 MH
Build Ramps = 20 MH
68 MH

10 x 20 Mat 12" Beams
Flame cut 10 - 12" Beams 10 x 0.5 = 5 MH
Place 10 - 12" Beams 5 men x 10 x 0.50 = 25 MH
Bolt 200 SF = 16 MH
Build Ramps = 20 MH
66 MH

(Continued)

Beam Concept repair

10 X 40 Mat

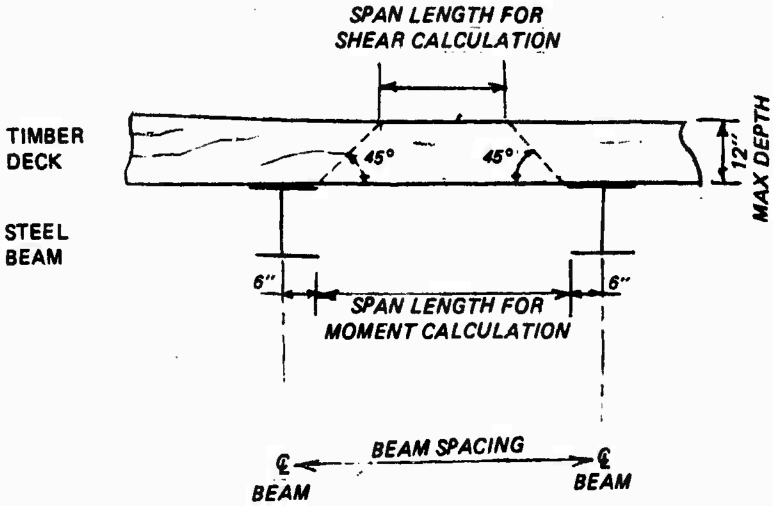
Flame cut beams		not done
Place 10 - 12" Beams	5 man crew X 0.75 =	40 MH
Bolt 400 SF		32 MH
Build Ramps		20 MH
		92 MH

110 [illegible] 12'

Timber deck design.

deck design limits.

12 x 12 is the largest timber member considered for availability reasons. 12 inches matches the thickness of most decks. If timbers are laid on top of decks, a 12 inch offset can be negotiated with end ramps.



Assume each 12 x 12 deflects seporately

Maximum moment resistance	57.6 ft kip	
Maximum shear resistance	14.4 kips	

For H.S. 20-40.

Max span length for 16 kip wheel load	12.5 ft	incl 15% impact
2-16 kip wheel loads 6' apart (transverse case)	11 ft	"
Max. span length for shear	Shear demand exceeds shear resistance Shear demand = 18.4 K > 14.4k	

The load should be spred to more than one timber by using a plywood or plank cover. This is probably necessary to protect bolts.

(Continued)

The shear demand increases quickly when the span exceeds 6 feet, so 6' is max span.

Max beam spacing = 6' + 2' + 1' = 9'

Max span allowed in shear

Twice the thickness of the deck material

Beam width

9 < 11 ft, ok for moment

max span, transverse moment.

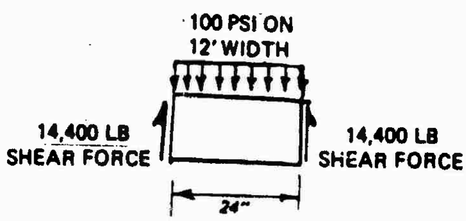
Check for uniform load, 1 kip/lf on 12"x12" timber. for 9' beam spacing, span for moment calculation is 8 ft

$$M = \frac{w l^2}{8} = \frac{(1)(8^2)}{8} = 8 < 57.6 \text{ OK}$$

Shear

$$V = \frac{6 \times 1}{2} = 3 < 14.9 \text{ OK}$$

For container handing vehicles, assume highest tire pressure is 100 psi. Information from WES indicates that stradle carriers use 130 tire pressure. NCEL researchers say that these vehicles can operate with reduced tire pressures for expedient purposes.



Assume the tireprint covers a 12" by 24" area

Max beam spacing = 2' + 2' + 1 = 5'

Max span allowed in shear

Twice the thickness of the deck material

Beam width

(Continued)

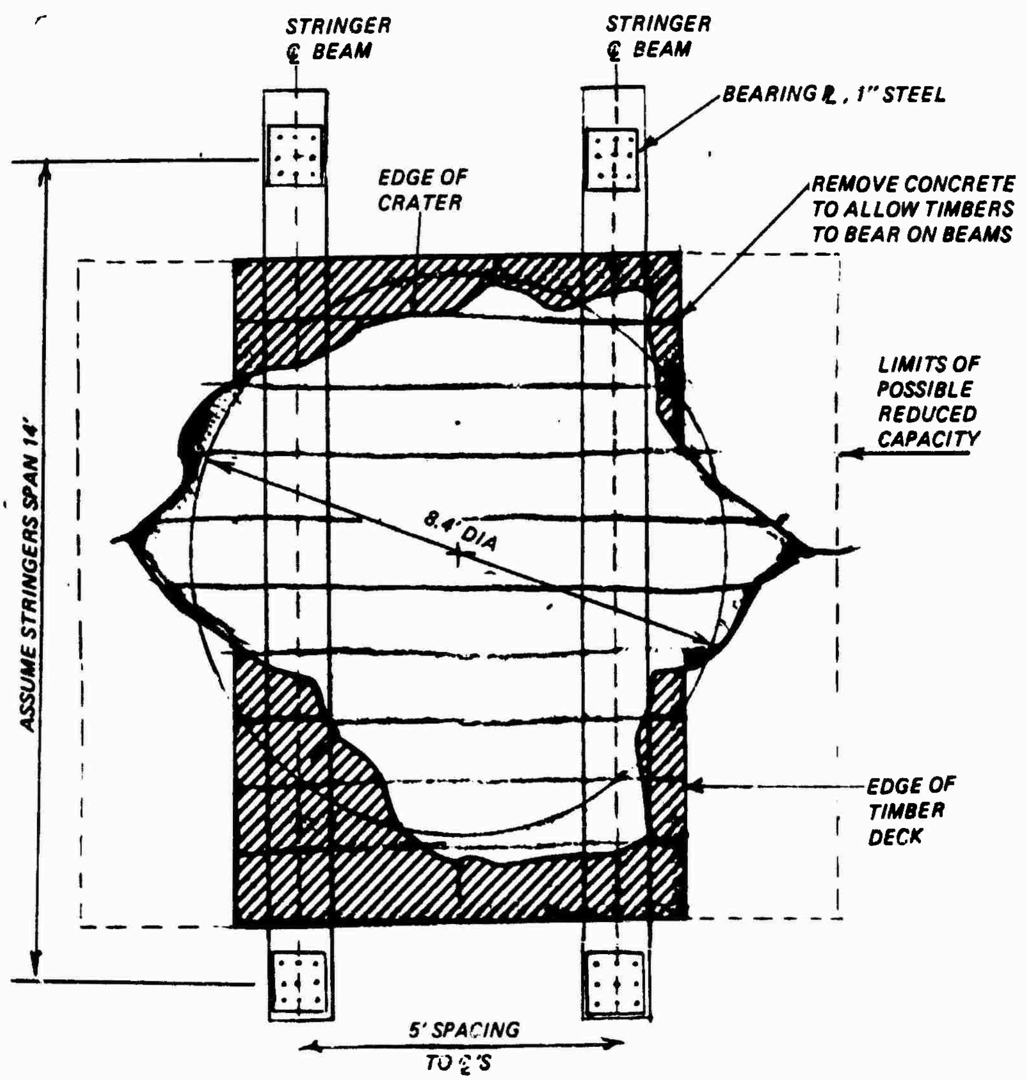
Check moment, span length for moment, 4'

assume 100 psi for entire span.

$$\frac{wl^2}{8} = \frac{19.4\,(4)^2}{8} = 28.8 < 57.6 \text{ OK}$$

8.4' circular nominal crater.

H.S. 20-40 Loading, max beam spacing = 9 feet, so ok to use a mat of 12x12's to cover the hole.



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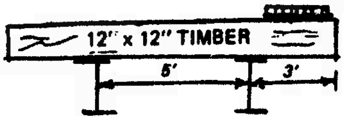
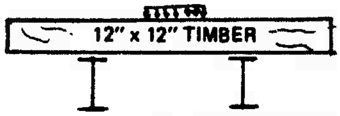
CONTAINER VEHICLE, NOMINAL 8.4' CIRCULAR CRATER
MOMENT ON TIMBER DECK

P & H 6250-TC 100 PSI ON CANTILEVER



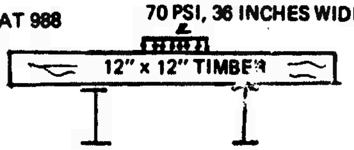
CASE I 28.8 FT-K < 56.7, OK

P & H 6250-TC 100 PSI, 30 INCHES WIDE ON MIDSPAN



CASE II 25 FT-K, OK

CAT 988 70 PSI, 36 INCHES WIDE AT MIDSPAN



CASE III 19 FT-K, OK

12 X 12'S OK

Stringers span 14'

Moment:

Possible critical cases for 5' stringer spacing

I. ½ Parallel lane load for P&H 6250-TC } 320 kips ←
II. ½ Transverse lane load for P&H 6250-TC }

III. Full transverse lane load for Cat 988 270 kips

Case I & II control Req'd $S_{X\,36ksi} = 107\ in^3$

Lightest section: W 21X55 $S_x = 110\ in^3$, ℓ_u, max unbraced length = 9.5' when $f_b = 0.66 f_y$ but this design is $f_b = f_y$, so ** caution** more bracing required. Bracing is required for the compression flange.

Select: W 12X 73 $S_x = 107\ in^3$, $\ell_u = 33.3$ a more compact section is safer for this purpose.

Max reaction from shear chart, use 10' span length since that is the deck length that the stringers support.

Case I. ½ lane load, P&H 6250-TC, longitudinal 94 k ←
Case II. ½ Transverse lane load P&H 6250-TC 86 k
Case III. Full Transverse lane load Cat 988 90 k

(Continued)

Nominal 8.4 Ft circular crater

Structural calcs:

<u>HS</u> <u>20-44</u> <u>loading</u>:

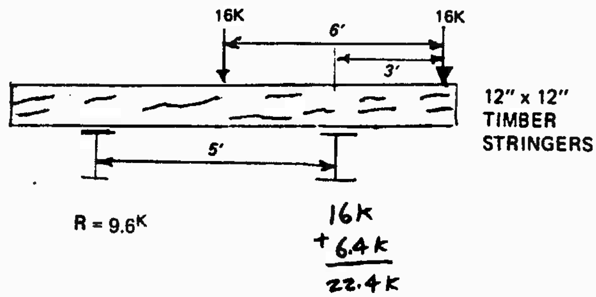
Check cantilever of timer deck

max cantilever − 3'

3X16 K wheel load = 48 k < 56.7 ok

Stringer beam design

Worst case:



$$M_{max} = \frac{PL}{4} \Rightarrow \frac{22.4(14)}{4} = 78.4 \text{ ft k. } \quad \frac{(12)\,78.4}{36} = 26.13$$

36 ← allowed f_b

$$\text{Req'd } S_x = \frac{(12 \frac{in}{ft})(78.4 \text{ ftk})}{36 \text{ kip/in}^2} = 26.13$$

Lightest section available is W 14 x 22 $S_x = 28.9$
Flange width is only 5"
For 12" Flange select W 12 X 65 $S_x = 88$
or HP 12 x 53 $S_x = 66.7$

Shear - no problem by inspection.

Max reaction − 16 k (one wheel on edge of crater over the stringer)

Beam could be hung using one 1" bolt for each end.

—— use 2 - 1" bolts.

(Continued)

Case I controls.

Use 4 - 1" bolts on each end of each beam.

Bill of Material

Item	Design load HS 20-44 Qty	Description	Weight	Container Handling Veh. Qty	Description	Weight
Lumber	5 ea	12"x 12"x 20'	8000 lb	← same		
	or 1600 bd ft	2"x 12"	8000 lb	← same		
Stringers	2 ea	W 12x53x16'	1696 lb	2 ea	W 12 x73x16'	2336 lb
Bearing Pls	4 ea	Pl 1x 20x 20	500 lb	← same		
Hanger Bolts	8 ea	1" ø x16"	say 100 lb	16 ea	1" ø x16"	say 200 lb
"J" Bolts	40 ea	say ½" x 16"	say 200 lb	← same		
			10,500 lb appx.			11,000 lb Appx.

Man hours

Description	Qty	Production Basis	Total MH
Concrete removal	27 cuft = 1 cu yd	0.5 CY/10MH	20
Debris removal		Guess	20
Drill holes in concrete for thru bolts	8 for HS 20 16 for CHV	8 holes/10 MH (means)	10/20
Hang beams using crane	2 ea	1.5 hours, each T.B. 420-16 & Guess 5 man crew	15
Deck with 12x12's	150 SF = 150 LF	NavFac P405 1000LF = 56 MH Table 4-37 4" decking Assume 1000 LF = 150 MH because of smallness of 2x12's	22.5

(Continued)

Man hour — Continued

Description	Qty	Production Basis	Total MH
Flame cut beams, Plates, cut bolt holes, etc	2ea	3 hr ea (guess)	10
select beams — move to site	2ea	5 man crew w/ crane, 1hr	5 MH
Select lumber move to site		5 man crew w/ crane 2hr	10 "
Cover with Plywood, clean up		guess	10 MH

Total 122.5/132.5

Safe guess 150 MH, each

Schedule time, 10 hr days Man hour loading:

Activity ↓ Hour →	Shift 1: 1	2	3	4	5	6	7	8	9	10	Shift 2: 1	2	3	4	5	6	7	8	9	10
Remove Debris	2	2	2	2	2	2	2	3	1	1										
Remove Conc.	2	2	2	2	2	2	2	3	1	1										
Select Beams	5/c																			
Cut & Prepare steel items		1	1	2	2	2	2													
Select Lumber, move		5/c	5/c																	
Precut Lumber				2	2	2	2	2												
Drill holes				2	2	2	2	2												
hang Beams									5/c	5/c	5/c	5/c								
Deck													5/c	5/c	5/c					
Men required	9	10	10	10	10	10	10	10	7	7	5	5	5	5	5					
Crane required	1	1	1						1	1	1	1	1	1	1					

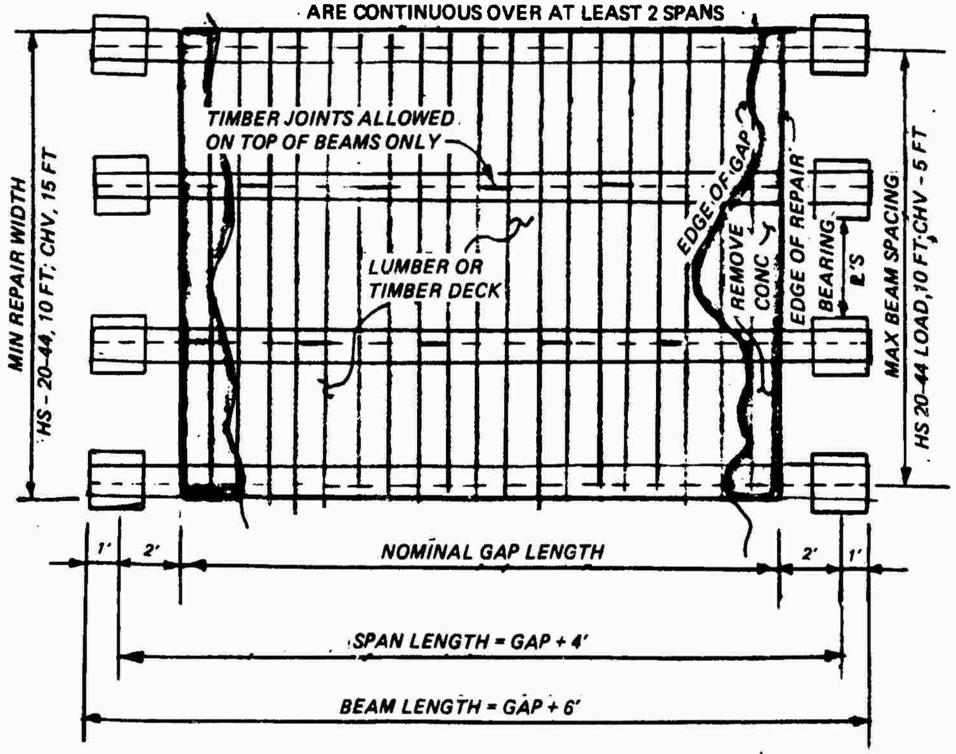
(Continued)

To bridge 13', 26', and 40' gaps, assume:

Min. width: 10' for HS-20-44 load
15' for CHV (wider deck required because of size of vehicle.)

Min Distance edge of sound concrete to attachment of beam - 2ft

Min beam spacing: 10' for HS-20-44 load
5' for CHV. (Note: Timbers come in 20' lengths, lumber in 8-10' lengths, beam spacing may be adjusted to make efficient cutting of lumber)



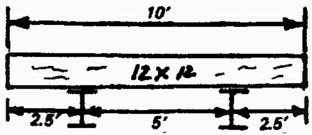
DESIGN LIMITATION
TIMBER & STEEL REPAIR

NOTE: THIS ARRANGEMENT ASSUMES THAT BEAMS ARE SUSPENDED BY BOLTS THAT PASS THROUGH THE UNDAMAGED DECK. ALTERNATIVELY, THE BEAMS COULD BEAR ON THE PILE CAP.

(Continued)

REPAIR MODULES:

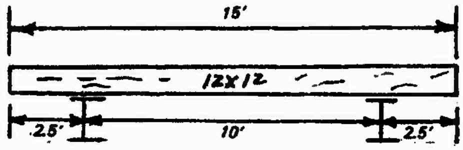
I.



FOR HS 20-44 Loading

This arrangement is desirable because 20' lengths of 12 x 12 can be cut in half to form the deck.

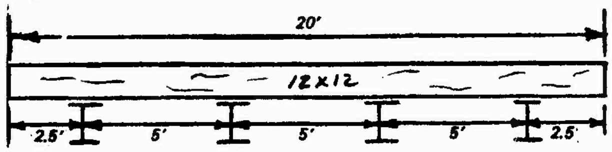
II.



For HS 20-44 loading

This arrangement is desirable because 2 beams can support a larger deck area.

III.



For CHV

This arrangement utilizes 20 foot timbers without cutting them.

Choose modules I & III for further calculations and comparisons to other repair systems.

Structural Demand, 5' stringer Spacing.	Case 1	Case 2	Case 3	Large Span example
Span of reduced Capacity	8.4 ft	13 ft	26 ft.	40 ft.
Span for Moment calculation	14 ft	17 ft	30 ft	40 ft
Max Moment demand Per Beam				
1000 PSF, 5' wide	122 ft-k	180 ft-k	562.5 ft-k	1000 ft-k
HS 20-44, ½ Lane, Longitud.	26 "	80 "	160 "	265 "
" Full transverse	24 "	85 "	220 "	310 "
Cat 938 Full Transverse	270 "	380 "	880 "	1240 "
P&H 6250-TC, ½ Long & Trans	320 "	435 "	1100 "	1500 "
Span for Shear & Reaction	10 ft	13 ft	26 ft	40 ft
1000 PSF, 5' wide	25 k	32.5 k	65 K	100 K
HS 20-44, ½ Lane Longitud.	18.4 K	18.4 k	26 k	32 k
HS 20-44, Full transverse	24 k	28.0 K	31 K	34 k
Cat 988 Full Transverse	90 K	104.0 k	126 k	say 140 k
P&H 6250-TC, ½ Long. & Trans	94 k	114.0 K	150 k	165 k

(Continued)

Design Comparison	Case 1	Case 2	Case 3	16' wide 40' long Long Span
HS-20-44 & 1000 lb/SF				
Critical Moment ft-k	122	180	560	1000
Req'd S_x in^3, $f_b = 36$ ksi	41	60	187	333
Lightest W section Available	W16x31	W16x40	W24x84	W33x118
Max unbraced length where $f_b = 0.66$ is allowed (L_c)	5.8	7.4	9.5	11.9
S_x in^3	47.2	64.6	212	359
Smaller W section (choice for scaliff)				
$d > 12"$ $b_f > 12"$	W12x65	W12x65	W12x161	W24x130
S_x in^3	88	88	222	339
L_c ft	12.7	12.7	12.7	14.8
Critical reaction	25k	32.5k	65k	100k
Number of bolts used	2 - 1"φ	2-1"φ	2-1½"φ or 4-1"φ	2-1½"φ or 4-1"φ
Container Handling Vehicle				
Critical Moment ft-k	320	435	1100	1500
Req'd S_x in^3 $f_b = 36$ ksi	107	145	367	500
Lightest W section Avail.	W21X55	W24X68	W33X130	W36X150
L_c ft	8.7	9.5	12.1	12.6
S_x in^3	110	153	406	504
Smallest depth Beam Section*	W12X79	W14X95	W24X145	W30X172
L_c ft.	12.8	15.4	14.8	15.8
S_x in^3	107	151	373	530
Critical Reaction Kips	94	114	150	165
Bolts reqd.	2-1½"φ or 4-1"φ	2-1½"φ or 4-1"φ	4-1½"φ	4-1½φ
Material Comparison				
Timbers 12"x12", 20' long before placement	5	5	20	40
Decking in place	80	80	300	640
Bolts				
H.S. 20-44	8-1"φ	8-1"φ	16-1½"φ	16-1½"φ
C.V.H.	8-1½"φ	8-1½"φ	32-1½"φ	32-1½"φ
Bearing P's ea. HS20-44/CVH	4 or 8	4 or 8	8 or 16	8 or 16
J bolts, ea.	40	40	350	350
Beams				
Original	Cut 40' in half	Cut 40' in half	full 40'	full 40'
In place	2-16' long	2-20' Long	4-32' long	4-40' long.

* Extremely heavy W14 sections may be rolled by special order. They are commonly used as columns. They are not considered here because of limited availability

(Continued)

Shipping
Weight Comparison

	Case 1	Case 2	Case 3	Long Span
Deck material lb.	4000	4000	32,000	64,000
Stringer beams				
HS 20-44/1000 PSF lb.	2600	2600	25,760	20,080
CVH lb.	3100	3800	23,200	27,520
Micellaneous (Appx.) lb.	1000 lb	1000 lb	4000 lb	4,000 lb
Total				
HS 20-44 & 1000 lb/SF lb.	7600	7600	62,000	88,000
CHV lb.	8100	8100	Say 62,000	95,000
Assumed repair area ft.	10x10	13x10	26x20	40x16
S.F.	100	130	520	640
Shipping weigh/SF of repair				
Total repair HS 20-44	76	58	120	140
CHV lb/SF	81	62	120	150
Beams & Misc. only (Timber avail in T.O, Misc=10#/SF) HS 20-44	36	28	60	41
CHV lb/SF	48	37	60	53

Shipping cubage

	Case 1	Case 2	Case 3	Long Span
Deck Material cu ft.	100	100	400	800
Stringer beams cu ft				
HS 20-44/1000 lb/SF	60	69	240	480
CHV	60	80	480	600
Misc	30	30	100	100
Total				
HS 20-44 & 1000 lb/SF	190	190	740	1380
CHV	190	210	980	1500
Cuft / SF Repair				
HS-20-44 Total repair	1.9	1.5	1.4	2.2
Beams only (add. 0.3 cuft/SF for misc.)	.9	.7	0.8	1.05
CHV Total repair.	1.9	1.6	1.9	2.3
Beams only	.9	.7	1.2	1.2

(Continued)

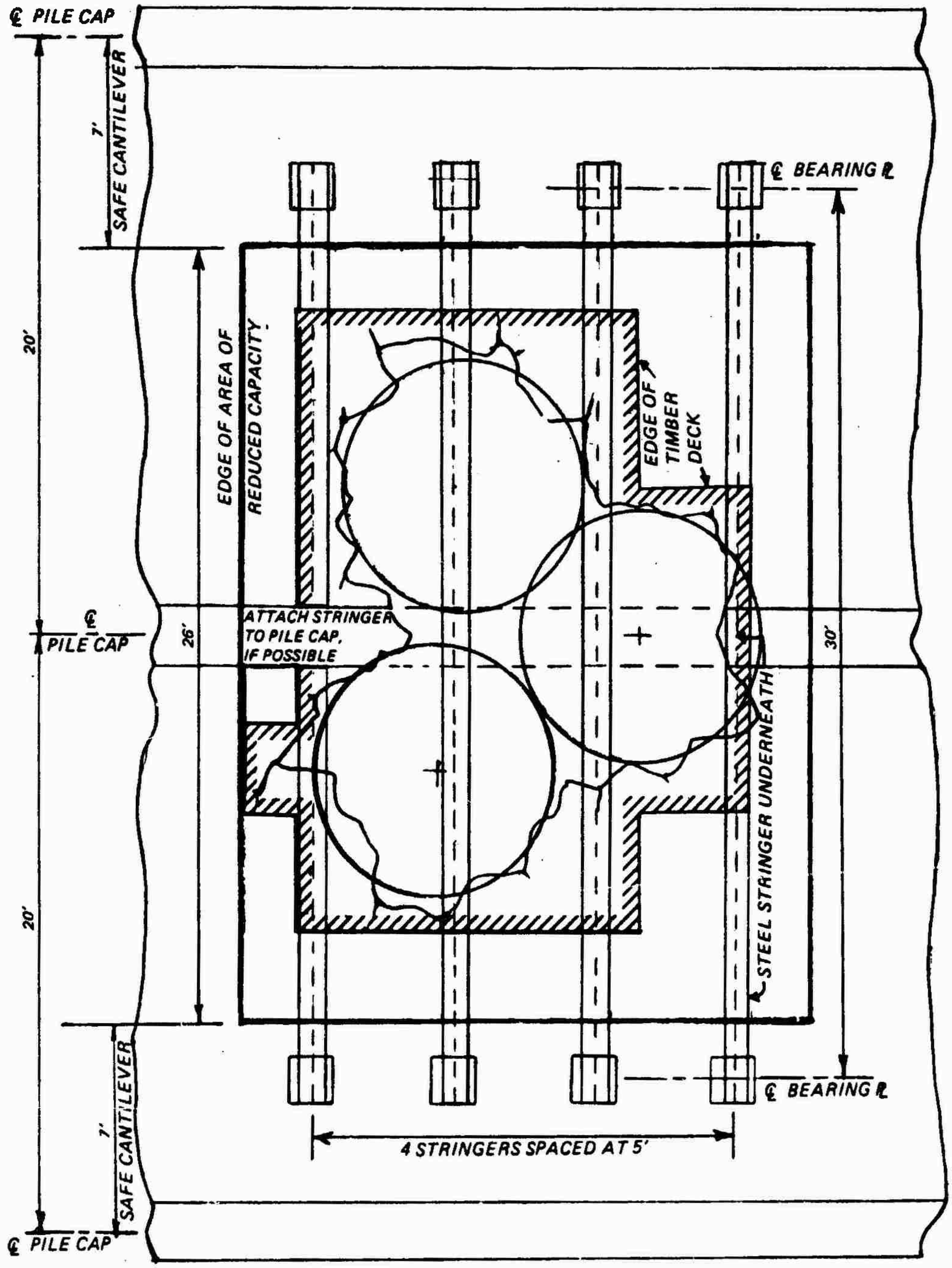
Man hours

		Case 1		Case 2		Case 3		Long Sp
Concrete removal	c.y.	1		1		4		4
Remove Conc. & Debris								
Jack hammer	M.H.	40		40		160		160
Saws, hydraulic breaker		20		20		40		40
Drill holes in Conc.	M.H.							
HS 20-44		10		10		20		20
CHY			10		10		40	40
Hang Beams Using crane	MH	15		15		40		40
Deck with 12'x12'	MH	25		25		100		100
Position & Prepare ~~materials~~ for installation	MH	25		25		50		50
Cover with plywood, cleanup	MH	10		10		40		40
Total (assume CHY's)	Jackhammer	125		125		430		430
	Saws, etc	105		105		310		310
Total MH./S.F.	Jackhammer	1.25		1.00		0.82		0.67
	saws, etc.	1.05		.70		.59		.48

Shedual Time

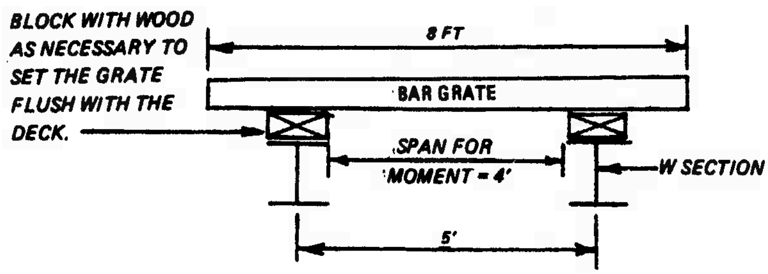
	Case 1	Case 2	Case 3	Long Sp
Remove concrete	10 hr	10 hr	10 hr	10 hr
crew size	4	4	4	4
Set Beams	3 hr	3 hr	8 hr	8 hr
Deck	3 hr	3 hr	12 hr	12 hr
Total	16 hr.	16 hr	20 hr.	20 hr.
Hr/SF	0.16 hr.	0.12	0.03	0.03

(Continued)



Timber and steel repair for Case 3 damage. Based on NICT at Pier 10 NAVSTA. Similar for Pier 7 NAVSTA

Use bargrates in place of timber 12x12's. Assume bargrates, 8'x 10' modules. Flame cutting of bar grates will be difficult due to space limitations. Assume full module sizes are used and concrete is cut back to accomodate modules.



Critical design case.

16 K wheel load @ midspan (15% impact) for HS 20-44, 1000 psf not critical for this

$M = \frac{4(18.4)}{4} = 18.4$ Req'd S_x f_b=20ksi = $11.04 in^3$

case 2, P4, Timber & steel calcs.

$25 \times 1.15 = 29$ Req'd S_x f_b=20ksi = $17.4 in^3$

Selection:

HS-20-44

Manufacture's literature (Engineered Grating, Inc.)

Bars $3\frac{1}{2} \times \frac{1}{2}$, $2\frac{3}{8}$ o.c. S_x=5.426/ft

32.2 lb/SF

for $S_x > 11.04$ Choose: $5 \times \frac{1}{2}$, $2\frac{3}{8}$ o.c. S_x = 11.34/ft

49.1 lb/SF

CHV

for $S_x > 17.4$ Choose: $5 \times \frac{1}{2}$, $1\frac{3}{16}$ o.c. S_x = 21.649/ft

91.2 = lb/SF.

(Continued)

Comparison with other methods:

~~Based~~ on timber deck & steel stringer method. Everything stays the same except, Shipping cubage and shipping weight.

	HS-20-44-1000 psf	CHV
shipping cubage	1/3 of deck material Stringers - same	1/4 of deck Material Stringers - same
shipping weight	same	2.25 times deck material weight

		Case 1	Case 2	Case 3	Total for berth
No. of Timbers Req'd for Timber repair		5	5	20	
Weight	lb.	4000	4000	16,000	
Cubage	cu ft.	100	100	400	

Adjustments:

Weight HS 20-44	lb.	0	0	0	0
CHV	lb.	+5,000	+5,000	+20,000	+65,000
Cubage HS 20-44	cu ft -	-66	-66	-262	-860
CHV	cu ft	-50	-50	-200	-650

Cost.

(Continued)

(Concluded)

Table D2. Bar Grates Based on Information from Corporate Brochure, Engineered Gratings, Inc., Houston, Texas, f_b = 20,000 psi

Span, in.	Moment, in-kips, 24 in. Wheel Width, Tire Pressure, psi			Required Sx, in.^{3}, 24 in. Wheel Width, Tire Pressure, psi			24 in. Wheel Width, Choice of Bar Grate, A × B(C) D(E)*, Tire Pressure, psi			Bar Spacing C to C, in.
	135	100	70	135	100	70	135	100	70	
12	29.2	21.6	15.1	1.46	1.08	0.76	2-1/4 × 1/4 (1.898) 17.8 (2.136)	1-3/4 × 1/4 (1.148) 14.0 (1.005)	1-1/2 × 1/4 (0.844) 12.1 (0.633)	1-3/8
							2-1/4 × 1/4 (1.411) 13.4 (1.588)	2 × 1/4 (1.115) 12.0 (1.115)	1-3/4 × 1/4 (0.854) 10.6 (0.747)	1-7/8
							3 × 1/4 (2.007) 14.3 (3.010)	2-1/4 × 1/4 (1.129) 10.9 (1.270)	2 × 1/4 (0.892) 9.7 (0.892)	2-3/8
18	65.6	48.6	34.0	3.28	2.43	1.70	3 × 1/4 (3.375) 23.6 (5.063)	3 × 1/4 (3.375) 23.6 (5.063)	2-1/4 × 1/4 (1.898) 17.8 (2.136)	1-3/8
							4 × 1/4 (4.548) 26.1 (9.096)	3 × 1/4 (2.509) 17.7 (3.763)	2-1/2 × 1/4 (1.742) 14.8 (2.178)	1-7/8
							4 × 1/4 (3.667) 21.6 (7.333)	3-1/2 × 1/4 (2.732) 16.5 (4.780)	3 × 1/4 (2.007) 14.3 (3.010)	2-3/8
24	116.6	86.4	60.5	5.83	4.32	3.02	4 × 1/4 (6.095) 34.0 (12.190)	3-1/2 × 1/4 (4.594) 27.4 (8.039)	3 × 1/4 (3.375) 23.6 (5.036)	1-3/8
							5 × 1/4 (7.107) 31.9 (17.766)	4 × 1/4 (4.548) 26.1 (9.096)	3-1/2 × 1/4 (3.415) 20.5 (5.976)	1-7/8
							5 × 1/4 (5.729) 26.2 (14.323)	4-1/2 × 1/4 (4.641) 23.9 (10.441)	4 × 1/4 (3.667) 21.6 (7.333)	2-3/8
36	234.9	174.0	121.8	11.75	8.7	6.09	4-1/2 × 3/8 (11.511) 55.0 (25.899)	5 × 1/4 (9.524) 41.7 (23.81)	4 × 1/4 (6.095) 34.0 (12.190)	1-3/8
							7 × 1/4 (13.929) 44.4 (41.787)	6 × 1/4 (10.234) 38.6 (30.702)	4-1/2 × 1/4 (5.756) 29.0 (12.592)	1-7/8
							6 × 3/8 (12.311) 45.7 (36.933)	7 × 1/4 (11.229) 36.5 (39.30)	5-1/2 × 1/4 (6.932) 28.6 (19.063)	2-3/8
48	356	264.0	184.8	17.80	13.20	9.24	7 × 1/4 (18.667) 58.2 (65.334)	6 × 1/4 (13.714) 50.5 (41.142)	5 × 1/4 (9.524) 41.7 (23.810)	1-3/8
							7 × 3/8 (20.788) 64.4 (72.758)	7 × 1/4 (13.929) 44.4 (48.7515)	6 × 1/4 (10.234) 38.6 (30.702)	1-7/8
							7 × 1/2 (22.227) 68.6 (77.794)	7 × 3/8 (16.756) 52.7 (58.696)	7 × 1/4 (11.229) 36.5 (39.301)	2-3/8

* A-Depth of bearing bar, in.; B-Thickness of bearing bar, in.; C-Section modulus, in.^{3}; D-Weight, lb/sq ft; E-Moment of inertia, in.^{4}

Prestressed Concrete Beam Concept

		Case 1	Case 2	Case 3	
Material Selection		3 Beams -20' long	3 Beams -20' long	7 Beams -40' long	
HS 20-44 @1000 psf.		12 x 36" slab 2.22 cy	12" x 36" slab 2.22 cy	21" x 36" slab w/ voids 2.73 c.y.	
CHV.		42" deep x 36" wide Box Beam 125 cu ft. 4.63 cy	← same	← same	
Shipping Weight					
H.S. 20-44	lb/Ea	9300	9300	22,878	
	lb/repair	27,900	27,900	100,146	412,000 $41,000
CVH	lb/Ea	19,375	19,375	38,750	
	lb/repair	58,125	58,125	271,250	793,000 $80,000
Shipping cubage					
HS 20-44	cuft	180	180	1470	3090 cuft
CVH	cuft	630	630	2940	8610 cuft
Man hours (does not include fabrication of beams)					
Remove concrete (use by ram & dymond saw)		40	40	60	
Move beams to site and place (5 man crew, 3hr, each beam)		30	30	105	
Place bearing assemblies 10 MH/Beam		20	20	70	
Total		90	90	135	945 MH

(Continued)

(Concluded)

Schedule Hours

		Case 1	Case 2	Case 3	Total
Remove Concrete	hr	10	10	15	
Set bearings		5	5	10	
Set beams		3	3	10	
		18	18	35	197
					say 200